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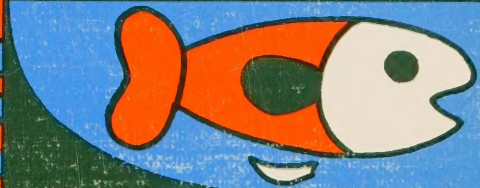
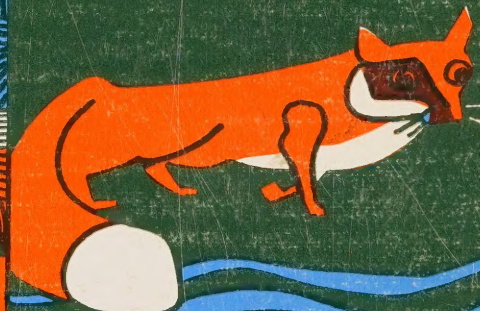


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TERRAIN EVALUATION WITH RESPECT TO
PIPELINE CONSTRUCTION, MACKENZIE TRANSPORTATION CORRIDOR
Southern Part, Lat. 60° to 64°N.

by

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Environmental-Social Program
Northern Pipelines

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The data for this report were obtained as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.

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*Maps	Surficial geology and geomorphology scale 1:125,000:	
	NTS 95 A, H, J, 85 E	Open File 93
	NTS 85 D, E, 95 A, B, G, M, I, J, K, N, O	Open File 158

* Maps not included with this report; the maps have been placed on Geological Survey of Canada Open File, and are available at user's expense from Riley's DataShare International, Limited, 631 - 8th Avenue S.W., Calgary, Alberta; order by Open File (O.F.) number.

1. SUMMARY

This report deals with the Mackenzie Valley and surrounding regions from the Provincial boundary at Latitude 60°, northward about 250 miles to Latitude 64°. The area consists of plains with broad uplands in the southern and eastern portions and rugged mountains in the west. In the south, the Mackenzie River winds its way toward the west, is joined by the Liard River near Fort Simpson, then continues westward to the base of the Nahanni Range where it swings north and occupies, for the most part, a broad valley between the Mackenzie and Franklin Mountains.

Moraine consisting of till is by far the most abundant surficial deposit and covers most of the plains and upland areas. Fine-grained lacustrine sediments cover wide areas adjacent to the Mackenzie River in the southern and northernmost areas. Eolian sand, glacial and post-glacial fluvial sand and gravel make up most of the remainder of surficial deposits.

One of the most important mapping units consists of organic deposits which form large tracts throughout the plains and upland areas. Smaller patches of these deposits are mapped along with surficial material. In the present study, the organic deposits are subdivided into two main varieties - bogland and fenland, although some deposits are transitional between these two categories. The former consists of peat plateaus and palsas whereas the latter comprises swampy depressions and ponds.

The southern Mackenzie Transportation Corridor is in the Discontinuous Permafrost Zone (Brown, 1969). In the southern part of the area, permafrost with ground ice is found within 2 feet of the surface in bogland, and extends downward through the organic deposits into the underlying till or lacustrine deposits, a depth of at least 15 feet. Ground ice also is found discontinuously below about 5 feet in fine-grained lacustrine deposits on either side of the Mackenzie River west of Fort Simpson under a rather thin organic cover and tall stands of timber. North of Willowlake River, permafrost and ground ice become much more widely distributed and permafrost is present not only in bogland areas, but also in most areas of fine-grained lacustrine deposits and in poorly drained till areas. In both cases, visible ground ice makes up a high percentage of the total volume in at least the upper ten feet. In the extreme north, lacustrine deposits contain permafrost to a depth of at least 50 feet. The only occurrence of permafrost in coarse-grained sediments is in post-glacial gravel and sand in valleys of the Mackenzie Mountains in the northwestern part of the area.

The major terrain hazards affecting pipeline environmental effects and engineering appear to be: 1) areas of fine-grained sediments that are subject to frost heaving, collapse caused by melting of indigenous ice, and flowage and slumping on

exposure, 2) thick organic deposits with high moisture content consisting of frozen bogland and unfrozen fenland that are subject to collapse upon thawing and frost heaving upon freezing, 3) areas with a high rate of surface runoff caused by impermeable frozen material near the surface which can cause flooding by collecting in ditches and other construction depressions, and 4) river crossings, where the approaches, scarps, and river bed characteristics may be hazardous.

The best routing, from a purely terrain standpoint is proposed. The only place it falls outside the broad corridor of interest to government and industry is in the north where the most acceptable pipeline route runs east of the Franklin Mountains.

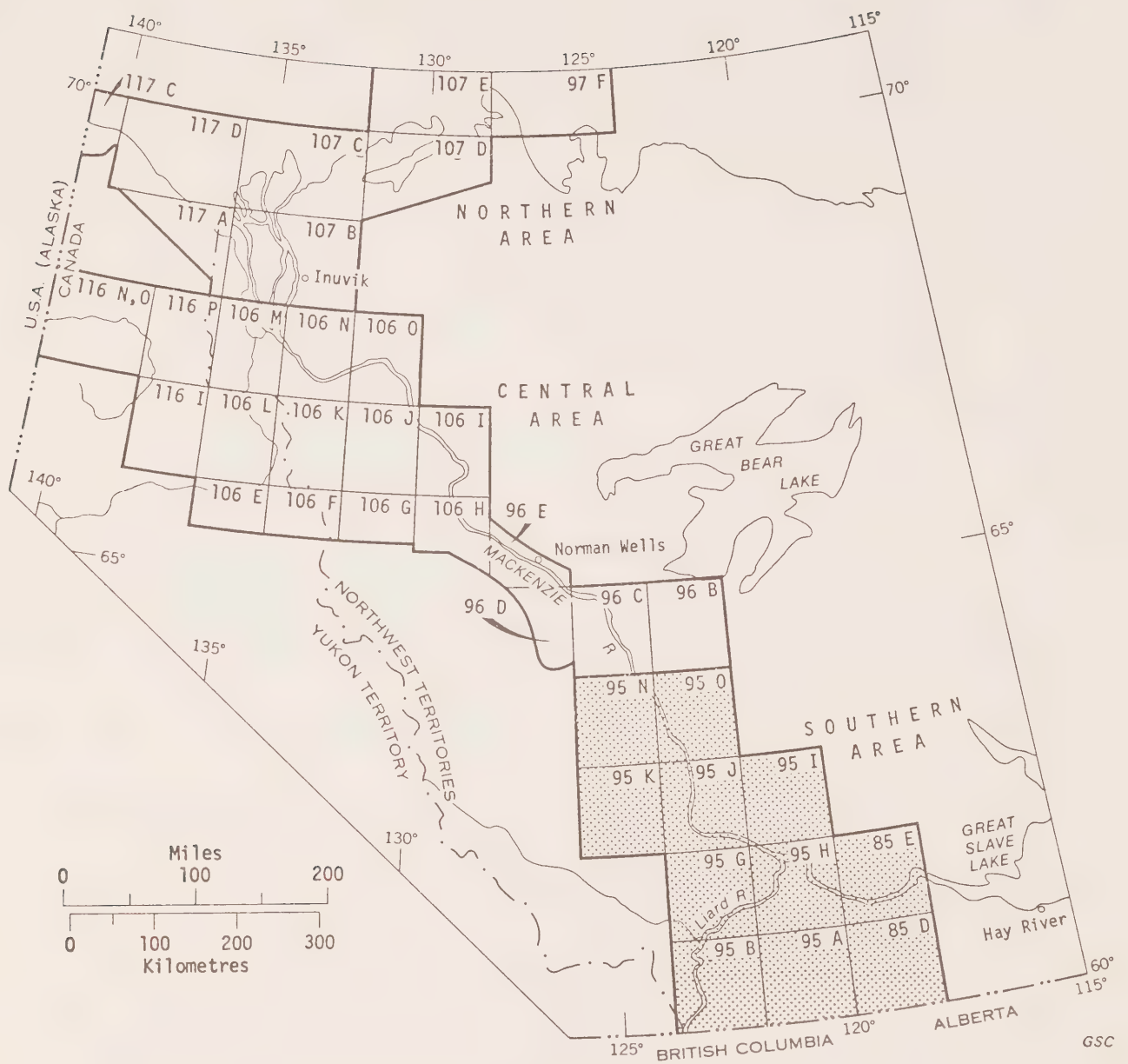
2. INTRODUCTION

Preliminary results of terrain evaluation of the Mackenzie Transportation Corridor (southern part), carried out during 1971 and 1972 are presented in this report. The objectives of the investigation were to map, describe and explain the unconsolidated deposits, landforms, permafrost, ground ice, and organic (muskeg) cover of the study area (Map-areas 85D, E, 95A, B, G, H, I, J, K, N, O) in order to: 1) provide areal knowledge of geology and terrain, with particular reference to the needs of government for terrain information in connection with land-use planning, pipeline proposals and other aspects of petroleum development and construction engineering, and 2) determine the Quaternary history of the region (Fig. 1).

This report deals essentially with the former objective. Surficial geology and geomorphology maps of the entire area are available (Open File 158) at the scale of 1:125,000 and should be consulted while reading this report. The principal part of the text describes only those areas that are included in a broad corridor which is of interest to industry and government for pipeline routes - both gas and oil. However, the discussion of the broad corridor is applicable in a general way to adjacent areas, therefore to the entire area investigated.

3. CURRENT STATE OF KNOWLEDGE

The surficial geology mapping of the area has been completed and enough laboratory analyses have been obtained, sections studied, and discussions held to present a broad picture of the terrain and how it will affect, in a general way, pipeline construction and related activities. What remains includes: checking and minor modification of the maps; laboratory analyses of selected samples for texture, lithology, moisture content and engineering properties; measuring and describing geologic sections; incorporating work from other scientific disciplines; and working out the Quaternary history of the area.



Northern Area	Rampton O.F. 21, 96, 119
Central Area	Hughes, <i>et al.</i> O.F. 97, 108, 167 Hanley, <i>et al.</i> O.F. 155
Southern Area	Rutter, <i>et al.</i> O.F. 158

Figure 1. Index map of terrain mapping Mackenzie Transportation Corridor

Prior to the present investigation, no surficial geological mapping had been carried out in the study area. The only reports of any consequence to this investigation are by Craig (1965), who studied principally the glacial lakes in the southern part of the area, and Brandon (1965), who carried out a reconnaissance study of groundwater hydrology and water supply covering the entire area mapped.

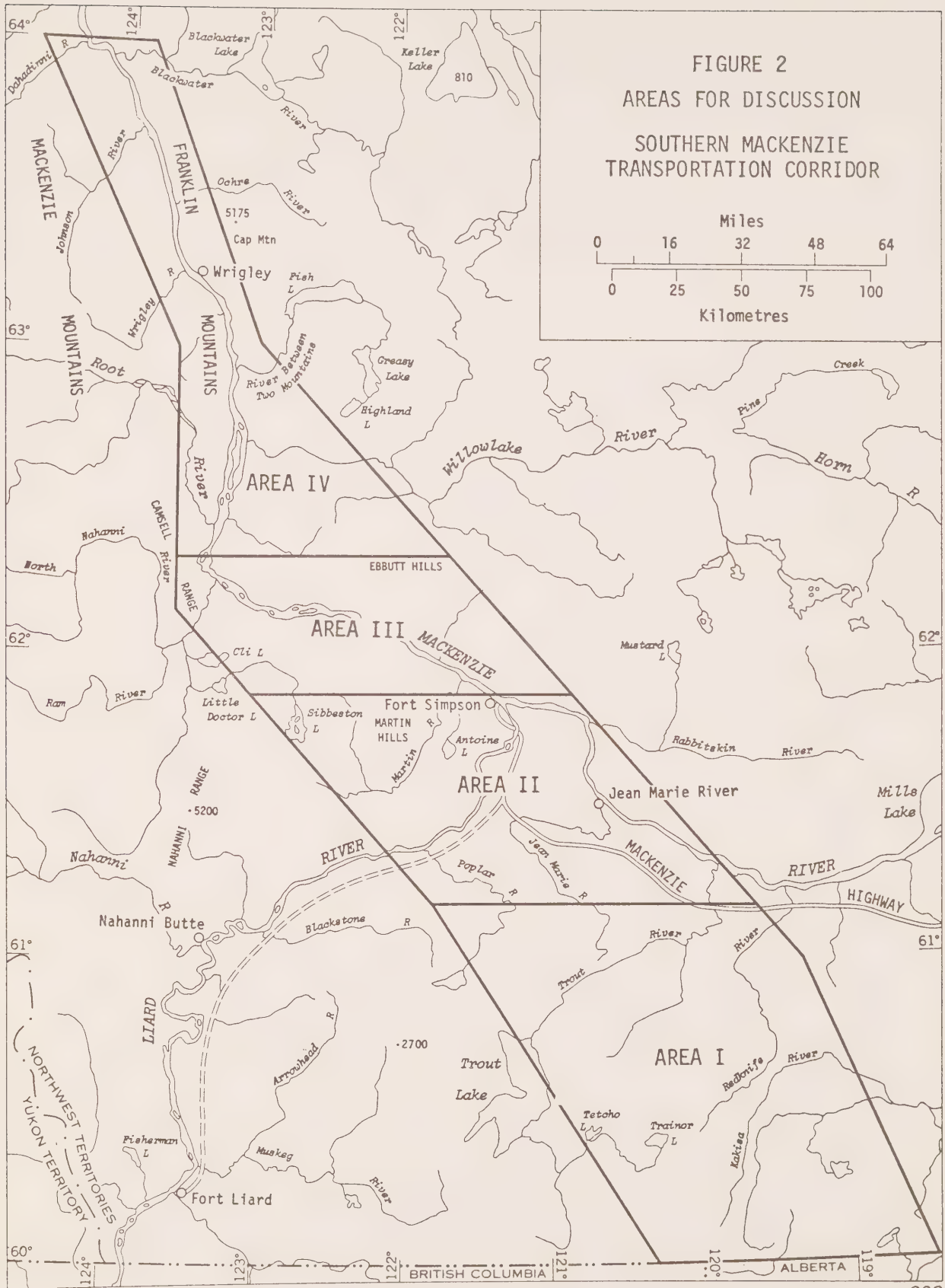
Bedrock reports and maps are available at various scales for the entire area (Douglas, 1959; Douglas and Norris, 1960a, b; Douglas and Norris, 1961, 1963; Stott 1960). They were used by the present authors to identify rock types in order to predict the lithology and texture of certain overlying surficial deposits and to add the basic lithology of the bedrock to our map-units where bedrock is exposed at the surface.

Reports have been completed by scientists who co-operated on this project. These include: L. Lavkulich (1972a, b), University of British Columbia, whose group studied soils, vegetation and land-form relationships in selected areas; C. Tarnocai (1973), Canada Dept. of Agriculture, who identified the soils that occur in the terrain map-units and investigated characteristics of organic terrain; and C. Crampton (1972), who mapped landscape units based on vegetation, landforms and frost characteristics. The present report contains only general information from these co-operating scientists based largely on discussions held in the field.

4. STUDY AREA

For the purposes of this report, the southern Mackenzie Transportation Corridor has been divided into four areas (see Fig. 2; Maps 1, 2, 3, 4) based on similarities of terrain, taking into account surficial deposits, distribution of permafrost and ground ice, and physiography. They form a broad north-south route roughly in the central part of the area mapped. The east and west boundaries are drawn close to the limits of the area of interest to government and industry for pipeline routes. The characteristics of each of these areas is similar to adjacent areas to the east and west so it is possible to extrapolate the discussion of one area to another.

The material is presented first by a general overview of an area, including a short discussion on the physiography, bedrock geology, distribution of surficial deposits and permafrost, and the major rivers that would have to be crossed by a pipeline. Surficial deposits are then dealt with more specifically in terms of distribution, morphology, thickness, lithology and texture. Included are notes on overlying organic deposits, distribution of permafrost and ground ice and surface drainage, which form an integral part of the behaviour of the deposits as a whole, especially when considering construction. A general description, and hazards or suitability, of potential



pipeline crossings of major rivers in the area are presented. Following are comments on the most suitable routing of potential pipelines and on construction problems and related activities for the area as a whole and for individual deposits.

Area I includes, for the most part, the western part of Kakisa River map-area (85D) and the eastern part of Trout Lake map-area (95A). The physiography and terrain characteristics of Area I are similar to those to the east and to the west as far as the Liard River, covering most of the geologically mapped area (Liard map-area 95B).

Area II, which is comprised largely of parts of the Fort Simpson (95H) and Sibbeston Lake (95G) map-areas, contains large areas of lacustrine and eolian sediments. These are generally different from the deposits found to the east and west, however, the terrain characteristics in the area of the Martin Hills in the northwest part of Area II are similar to those found as far west as the Nahanni Range (Sibbeston Lake map-area 95G). The eastern part of Area II consists of till and lacustrine deposits with permafrost characteristics similar to those found to the east covering the major part of the Mills Lake map-area (85E).

Area III, comprising small parts of the Fort Simpson (95H), Sibbeston Lake (95G), Camsell Bend (95J), and Bulmer Lake (95I) map-areas, has deposits consisting largely of till and lacustrine deposits. Terrain characteristics in the northeastern part of Area III, consisting mainly of a till plain, are very similar to those found toward the north in the Bulmer Lake map-area (98I).

Area IV covers mainly the Camsell Bend (95J) and Wrigley (95-0) map-areas and contains lacustrine sediments and till that are similar in character to other areas of the corridor but with more widespread permafrost and ground ice. East of the Franklins, outside Area IV but within the Wrigley map-area, the terrain consists largely of till similar to that found to the south but with permafrost characteristics similar to that of Area IV.

Mountainous regions are found in several of the western map-areas, particularly the Root River (95K) and Dahadinni (95N) areas. They are not described as these areas are unsuitable for pipeline routes. However, the surficial deposits within the mountains were mapped for completeness, and the lithology of the bedrock indicated.

5. METHODS AND SOURCES OF DATA

The project was initiated in May, 1971 with interpretation of surficial geology from aerial photographs (approx. 1 inch to 1 mile) of the Camsell Bend (95J), Fort Simpson (95H), Mills Lake (85E), Trout Lake (95A) and the north half of Fort Liard (95B) map areas.

Airphoto information then was transferred to 1:125,000 mosaics of the respective map-areas. Two geologists, Gretchen Minning and N. W. Rutter, and three assistants, John Netterville, Ron Dilabio and Peter Ostergaard, worked in the field from June through August, 1971. R. W. Klassen led the party for three weeks when N. W. Rutter was absent. Helicopter support was utilized mainly for ground checking airphoto interpretation and for sampling for later analysis. Major sections were investigated, measured and sampled.

In addition to helicopter support, boats were utilized on the major rivers to investigate sections exposed by river erosion and trucks for cuts along existing highways.

C. Crampton, Department of the Environment, was assigned to the field party with the task of delineating landscape units according to vegetation (Crampton, 1972). L. Lavkulich and associates, University of British Columbia under the ALUR program, worked on soils-vegetation-landform relationships in areas designated by Rutter in the Camsell Bend, Trout Lake, Mills Lake and Fort Simpson map-areas (Lavkulich, 1972b).

During the winter of 1971-72, the surficial geology and geomorphology mosaics were modified from information accumulated in the field and submitted for Open File (93) for public use. Also laboratory work was begun with completion of texture analyses on fine-grained lacustrine sediments and till.

During the spring of 1972, surficial geological interpretation from aerial photographs was initiated for the following map-areas: Wrigley (95-0), Dahadinni (95N), Bulmer Lake (95I), Root River (95K), Sibbeston Lake (95G), Kakisa River (85D), and the southern half of Fort Liard (95B). This information was then transferred to mosaics for field checking.

In 1972, the field party was enlarged to include two geologists, A. N. Boydell and N. W. Rutter, and four assistants, P. Ostergaard, A. Cooper, D. Ginter and P. Griffin. In addition to the equipment used the previous year, a Smit portable drilling unit was added in order to core organic terrain and fine-grained sediments to determine deposit thickness, permafrost depth and thickness, absence or presence and nature of ground ice, and characteristics of the organic terrain and surficial geological deposits. A portable laboratory unit also was used to analyse samples for color, grain size, moisture content, and to determine Atterberg limits.

C. Crampton again joined the field party to continue his work on the remaining map sheets and L. Lavkulich and his associates spent about three weeks investigating a designated area on the Wrigley and Dahadinni sheets (Lavkulich, 1972b). C. Tarnocai, Dept. of Agriculture, joined the field party for the first time, with the assignment

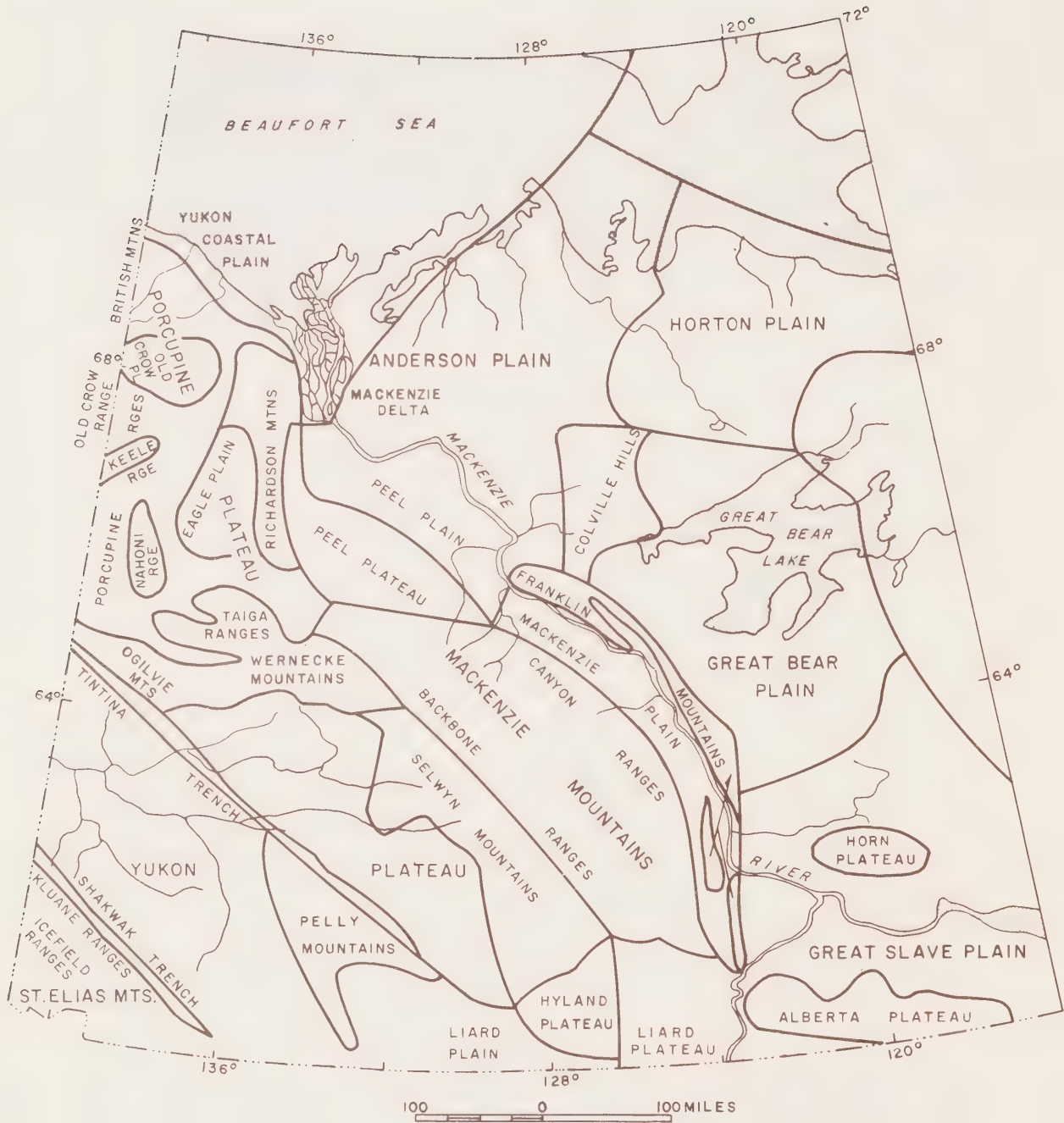


Figure 3. Physiography of Yukon Territory and western District of Mackenzie (after Bostock, 1969)

of identifying soils and investigating organic terrain with particular attention to the distribution of permafrost (Tarnocai, 1973).

During the winter of 1972-1973, the last of the surficial geology and geomorphology mosaics were modified, corrected and completed. These were then transferred to Cronoflex transparencies as were the previous year's maps in order to produce prints for Open File (158). Laboratory work started in the field was continued and completed in the laboratory at Calgary.

In addition to the data accumulated by the authors and associates directly or indirectly involved in this project, subsurface data obtained by companies also have been incorporated in this report. Appendix A lists the companies, accompanied by some of their drillhole information.

R. O. van Everdingen (Inland Waters Directorate) spent about a week and a half in the field during 1973 investigating groundwater discharge in selected areas. This report appears in Appendix B.

The writers hereby acknowledge the significant contribution to the success of this project by all those who co-operated, often under trying circumstances.

6. GLACIAL HISTORY

The area investigated in this project includes the eastern part of the Mackenzie Mountains and the southern part of the Mackenzie Plain and Franklin Mountains. To the east, a large portion of the Great Slave Plain, interrupted by parts of the Alberta and Horn Plateaus, is included, as is the southern portion of the Great Bear Plain, northern tip of the Fort Nelson Lowland and the easternmost extent of the Liard Plateau (Fig. 2; Bostock, 1969).

Stratigraphic and morphologic evidence indicates that the area was invaded at least twice from the east by Laurentide ice. The first and most extensive is recorded by a grey-black stony till exposed as the basal unit in sections at various locations in the study area, most commonly along tributaries of the Mackenzie River. Glacial erratics considered to have been deposited by this advance, are found to an elevation of 5,000 feet in the Mackenzie Mountains indicating that the glacier crossed the summit areas of the mountains in at least the eastern portions.

The second Laurentide advance is recorded at the surface of the mapped area by light grey-brown stony till, locally variable in texture and separated from the lower till by an erosional surface or stratified sand and gravel (Fig. 4). The ice, apparently thinner than during the earlier advance, was controlled topographically to

the extent that it was deflected by mountain ranges both to the southwest and to the northwest, the area of deflection being in the Sibbeston Lake map-area (95G). Tongues of ice were able to penetrate west through gaps in the mountain ranges as indicated by glacial deposits assigned to this advance.

Retreat of the last Laurentide ice sheet was northeastward in the south, and eastward in the north. A number of the eastern valleys of the Mackenzie Mountains acted as meltwater channels as the ice pulled back (Fig. 5). Ice-dammed lakes were common, resulting in thick lacustrine deposits in relatively small areas in many valleys (Fig. 6). Further pullback into the plains area created large-scale damming, forming major lakes along the Mackenzie and Liard River Valleys. Considerable thicknesses of fine-grained sediments were deposited including a major delta formed at the mouth of the Liard River depositing sand over a wide area around Fort Simpson. Beaches were formed, some of the best developed at elevations of about 850 feet, bordering the Mackenzie in the eastern part of the area. As the ice pulled further back onto the plains and uplands, till was deposited forming wide areas of hummocky moraine and distinct moraine ridges that indicate former ice front positions. Radiocarbon dates from peat overlying till suggest that ice had withdrawn from the area at least 8,280 years before present (GSC-1837).

The only evidence that Cordilleran ice ever penetrated into the mapped area is in the form of till without erratics derived from the east and abandoned meltwater channels found in the western part of the Root River (95K) and perhaps Dahadinni (95N) map-areas.

7. RESULTS

7.1 Area 1 - Southern Region: Trout and Kakisa Rivers (60°00' to 61°10'N Lat.; 118°30' to 121°50'W Long.)

Map Sheets - Western part Kakisa River (85D)
Eastern part Trout Lake (95A)
Southernmost part of Fort Simpson (95H)
Southwestern part Mills Lake (85E)

7.1.1 Overview

Area I (Fig. 2, Map 1) comprises two broad uplands which are separated by the two major rivers of the area - the Kakisa and Trout. Elevations in the area vary from a low of about 900 feet in the northeast to a high of about 2,650 feet in the summit areas of the uplands. The regional relief is rather low, the maximum being in the order of 1,700 feet in 35 miles.

The uplands and intervening lowlands are formed by eroded bedrock, almost entirely of the Lower Cretaceous Fort St. John Group. Exceptions are found in the upland south of Trainor Lake which may consist of the Upper Cretaceous Dunvegan Formation, and in the low area in the northeast part where Upper Devonian rocks crop out. The Fort St. John Group consists of a high percentage of shale containing up to 70% illite (hydromica) and about 30% mixed layered vermiculite and montmorillonite. The shale is soft and fissile and therefore highly erodible and under certain conditions fails easily. Viewed from a distance, weathered sections appear as Pleistocene glaciolacustrine silts. In contrast, the hard Lower Cretaceous shales of the Foothills of Alberta form steep, relatively unweathered cliffs. The higher relief of the upland south of Trainor Lake suggests that it is underlain by the Dunvegan Formation. It probably consists of friable sand, siltstone and shale. The Upper Devonian rocks forming the lower terrain in the northeastern part of the area consist of hard, highly resistant cryptocrystalline and clastic limestone.

Bedrock outcrops are scarce in Area I with the exception of the highly resistant limestone which crops out at the surface in the northeast. Along the two major rivers, the Kakisa and Trout, no bedrock outcrops have been recorded except in the northeast where the Trout flows through limestone.

Overlying the bedrock are thick surficial deposits, mostly till, forming typical landforms such as hummocks and ridges. The deposits vary in thickness, averaging over 20 feet. They are thickest at lower elevations and thin over upland areas and in the area of limestone. Details of the surficial deposits are presented below but it should be pointed out that the finer fraction of the till, comprising about 80-95% of the total, is almost a direct reflection of shale bedrock, and therefore highly subject to failure. In general, the bulk of the till consists of approximately equal amounts of silt, clay, and sand. The sand content increases toward the southeast where Upper Cretaceous sandstone and siltstone become more abundant.

Area I is located in the Discontinuous Permafrost Zone. Even though it is in the southernmost area discussed, permafrost is present although sporadic, controlled mainly by organic terrain, local drainage, texture of surficial deposits and elevation.

7.1.2 Surficial Deposits

7.1.2.1 Till

Most of Area I is blanketed by varying thicknesses of till. The regional relief is controlled by bedrock, forming broad uplands, and various types of till morphology control the local relief. The till

is crossed by many abandoned meltwater channels and streams trending in various directions but predominantly toward the northeast. Many areas have widespread but discontinuous patches of organic terrain varying between bog and fen peat. No other features or deposits of importance are present.

The till forms a relatively featureless plain over the entire area. The surface consists of subdued hummocks with a few feet of relief and deranged surface drainage, or integrated drainage along shallow gullies if on slopes. As indicated on the maps, areas of flutings and drumlinoid ridges, hummocks, rolling terrain, and ridges or combinations of these are common (Figs. 7 and 8). Drumlins and flutings are restricted to relatively small areas in the central and southern parts of the area. They form parallel ridges in a south-westerly direction with heights averaging 20 to 40 feet, commonly with deranged drainage but also forming integrated trellis patterns. Hummocky and rolling terrain are represented in relatively few areas except in the southeast where hummocks cover the major part of the summit area of the uplands. The topography forms a deranged drainage system with hummocks up to about 30 feet high.

Ridges, mostly crevasse fillings, are present in subparallel to parallel patterns throughout much of the area, but are especially prevalent in the northern part where they form patterns trending to the south and southwest. Ridges are generally about 5 feet high, but heights of about 30 feet may be reached. On aerial photographs, the ridges usually appear much more pronounced because of high stands of timber on the better-drained crests.

The thickness of the till varies, with the thicker deposits being found in the lower lying terrain and the thinner deposits on the summit areas of the uplands. Data from seismic shot holes in the southeastern part indicate at least 40 feet of till whereas shallower test drilling, along a northwest-southeast line in the central part of the area, shows minimum thicknesses of about 12 feet. Thus, the principal surficial deposit that will be encountered during pipeline construction is till, probably with an average thickness of about 20 feet.

The texture of the till varies, but not substantially, as the texture is a reflection of the widespread underlying shale (Fig. 9). Coarse material (> 4 mm, pebble-size or larger) rarely exceeds about 5% of the total, except in crevasse fillings, deflated surfaces and locally where the terrain is underlain by resistant bedrock. The few samples that have been analyzed contain roughly equal proportions of clay, silt and sand. Liquid and plastic limits are of the order of 25% and 17%, respectively, whereas the water content by weight varies from about 9% to 19% at various depths from the surface to about 20 feet.

It should be mentioned that, in the northern part, there is often a discontinuous coating of silt and sand over the till ranging up to 3 feet thick but usually averaging about 1 foot. The origin of this material is in some doubt but its inferior engineering properties are clearly evident.

The climate, poor permeability of till, irregular topography and deranged drainage of some till surfaces have resulted in the widespread development of thick organic terrain. The occurrence varies between small patches of a few acres to tracts of several square miles. In Area I, bogland and fenland occur separately or mixed and in all stages of intermediate development (Figs. 10 and 11). Thick organic material occurs generally in depressions on rolling or irregular surfaces that are of low relief or generally sloping. In well-drained areas, both on the local scale and regionally, organic terrain is less than 4 feet thick. Drilling in bogland has indicated a maximum thickness of 12 feet, with the average amount 9 feet. There is a thinning trend from south to north.

The presence or absence of permafrost and ground ice in this area is linked directly to the development of organic terrain occurring in the form of bogland. Bogs are usually elevated 2 or 3 feet to as much as 15 feet above the surrounding area. Depth of maximum seasonal thaw (end of August) varies from 13" to 27" with permafrost extending to a depth of at least 2 or 3 feet below the organic deposit. Moisture content is extremely high with values varying between 200% and 800%*.

Passing from bogland into adjoining fenland and ponds, the depth of the active layer increases rapidly. The presence or absence of permafrost depends principally on the stage of organic development. Probing in ponds, the writers detected no frost for at least 9 feet (the length of the probe) whereas, in fenland, if permafrost is present it is quite deep, over 6 feet, but it is generally lacking altogether.

Ridges and hummocks, typical till morphology, are well drained and contain no permafrost or ground ice. In relatively featureless, flat-lying till plains covered by about 4 feet of organic matter, there may be adequate insulation to cause permafrost and subsequently ground ice near the surface.

Characteristics of surface drainage depend upon the presence or absence of shallow permafrost, permeability-porosity of the surficial material, thickness and type of organic cover, local relief, regional slope and, of course, the climate. In Area I, several of these factors

*The ratio of the weight of water to the weight of solids in a given mass of soil; expressed as a percentage of the weight of oven-dried soil.

result in a high volume of surface runoff during spring melting and during heavy summer rains. In general, the till has high porosity and low permeability which in itself promotes surface runoff. Till morphology, which causes deranged drainage, results in high runoff in restricted areas with collection and seepage in depressions. This promotes organic growth and subsequent permafrost and high volume ground ice when it reaches the stage of bogland and is, therefore, impermeable. A good example of surface drainage characteristics in Area I is found on the summits of the uplands in the southern part of the area where hummocks have high local relief. Most of the terrain, however, has well-integrated drainage, with gentle slopes and an organic mat less than four feet thick (although with discontinuous patches of thick bogland and fenland). Surface runoff is a hazard only in the spring when the volume is high and seasonal frost forms an impermeable barrier. During the summer, the organic matter and till are able to absorb much of available moisture, restricting surface runoff.

7.1.2.2 Other Deposits

The only other materials of any importance in Area I are sand and gravel deposited in abandoned meltwater channels and as crevasse fillings.

Meltwater channels are concentrated in the northeastern part of the area, forming troughs up to one hundred feet deep and 1/4 to 1/2 mile wide. The channels form, for the most part, a parallel to sub-parallel belt trending northwestward that enter into the present-day drainage system that flows to the north. Other meltwater channels are scattered throughout the area with an extensive broken network associated with the present-day Kakisa River.

The deposits associated with these channels have not been investigated fully. It is assumed that they are coarse grained, well drained, with no permafrost or ground ice. However, silting has taken place in some since post-glacial time and, therefore, they may support thick organic cover and subsequently permafrost and ground ice.

The other source of gravel and sand in Area I is in crevasse fillings, found mainly in the northern part of the area. The materials comprising these ridges range from coarse, poorly sorted gravel to till, which is coarser than the normal till of the area.

Lacustrine silt and clay are clearly minor deposits for this area. Damming occurred as the ice pulled back to the northeast during final deglaciation; however, the paucity of deposits suggests that the duration of damming must have been short and that ample diversion channels were present. The only occurrences recorded are adjacent

to the lower reaches of the Trout River and small patches associated with hummocky moraine. Where overlain by bogland, they are subject to permafrost and high ground ice content.

7.1.3 River Crossings

The only major rivers in Area I are the Trout and the Kakisa Rivers. Special consideration will be necessary regarding the best pipeline crossings.

7.1.3.1 Kakisa River

The upper part of the Kakisa, which flows toward the north, meanders in a narrow belt with relatively high banks. The scarps decrease in height from about 100 feet in the upper reaches to 30 or 40 feet farther down the river. The depression occupied by most of the upper part of the river appears to have been a meltwater channel and is, therefore, relatively broad, up to 1/2 mile wide. The terrain on either side of the channel is relatively stable, consisting either of drumlin or fluting-like structures which are well drained, often made up of compacted till, coarse meltwater channel deposits that have been dissected by the present-day river, or till, forming a part of a plain with overlying discontinuous patches of bogland.

Continuing northward, the river swings to northeast, then east, and finally southeast with bank heights decreasing from 30 to 40 feet to less than 20 feet toward the eastern edge of Area I. The energy remains about the same but an increase in water volume has resulted in a wider meander belt, in some places up to a mile wide, thus erasing any sign of a meltwater channel if one was ever present. The terrain of the bordering area is composed of till, forming a plain with overlying discontinuous patches of bogland.

Both the southern and northern parts of the Kakisa River possess advantageous features for pipeline crossings. The southern part generally has more stable banks whereas the northern part has lower scarps but they are composed of less stable material. Probably the greatest potential problem in both areas is the undercutting and bank erosion caused by the meandering nature of the stream. Even though the stability of the till varies in the two sections, and in general it is not particularly stable because of its fine-textured nature, it is fairly well drained and contains no permafrost or ground ice. The northern section, where the scarps are lower, seems to present more advantageous river crossings. Locally, the crossing should be where the meander belt is narrow and where there is little chance of lateral erosion due to meandering, flooding, or damage from ice break-up.

7.1.3.2 Trout River

The Trout River in Area I is not unlike the Kakisa. It is near grade, flowing through an area of unconsolidated deposits. As the Trout River is influenced more than the Kakisa by the base level of the Mackenzie River, scarps may reach heights of over 100 feet. However, the average height of the banks, 20 to 30 feet, is lower than on the Kakisa.

The Trout River can be divided into two segments based upon meandering characteristics - the western part meanders very little whereas the east, at lower base level, forms a narrow meander belt up to 1/4 of a mile wide. In the western part, the river is incised in a till plain with closely spaced, parallel to subparallel ridges formed of crevasse fillings. In the east, where the river meanders more widely, it passes through a narrow belt of thin lacustrine silts overlying till. The choice for a pipeline crossing is clearer for the Trout River than for the Kakisa. The western part of the Trout is preferred as there is little meandering and less chance of undercutting. Also the till is well drained, with little possibility of ground ice content, and has better performance characteristics than the lacustrine silts found farther downstream. The exact crossing location should be where the till is the coarsest, where present-day flood plain contains coarse material and where river erosion is at a minimum, both laterally and vertically.

Other rivers in the area are minor and should not cause major crossing problems. However, approach problems may be significant where misfit rivers occupy abandoned meltwater channels with high scarps.

7.1.4 Pipeline Construction Problems

A significant number of terrain factors may cause detrimental effects to the environment and the pipeline, both during and after construction. Mixed areas of bogland and fenland probably offer the greatest hazard. The irregular topography, frozen and unfrozen nature of the material, deranged drainage, high moisture content, and the general inherent characteristics of organic matter all add to the problems. Probably the single most important factor outside of damaging and altering the environment is volume changes due to the melting of ice and freezing of water. Melting of ground ice in the till by a warm oil pipeline or formation of ground ice by a cold gas pipeline may cause pipe rupture. As discussed previously, indigenous ground ice probably is present only below thick deposits of bogland and, although most of Area I is underlain by fine-textured till, bogland is not so extensive that it is an unavoidable problem.

Another factor that may cause damage to the environment and to the pipeline is mass movement of material downslope. As mentioned, the till in Area I is generally fine grained containing a high percentage of silt and clay. Under the best of conditions, this material has relatively poor performance. If the vegetation mat is removed either by construction activity or some other method, such as a forest fire, the material is subject to massive flowage if water saturated, and to gullying by runoff, even on slopes as gentle as two degrees.

Ditching and burying activities may cause erosion hazards when crossing abandoned meltwater channels and major rivers where the bordering scarps consist of till.

Irregular topography, such as a hummocky area with deranged drainage, will result in excessive ditching and complicate the construction procedure.

Thus the problem is to select the routing through Area I, based on terrain considerations, that offers the fewest detrimental factors in pipeline construction and land damage, and that enters Area II where the most suitable routing in that area begins (Fig. 2).

Starting from the south, the best route for pipelines would run through the broad valley of the Kakisa River below the higher areas of the uplands to the east and to the west. If the pipeline is on the east side of the river, a crossing should be south of the east-central area that contains numerous lakes and meltwater channels. The proposed routing then would leave the Kakisa valley and run north and then northwest. It is then split into two segments to run on either side of the Redknife Hills. The western, and preferable, routing lies between the Redknife Hills and Trainor Lake; the second between the base of the Redknife Hills and the lake and meltwater channel region to the east. The routing again merges past the Redknife Hills and follows a broad path to the northwest. Where it crosses the Trout River, the route is about 12 miles wide, stretching from a point 12 miles northeast of Trout Lake eastward to where the river begins to dissect lake deposits, and meanders more frequently.

7.1.5 Views and Comments

In general, Area I does not offer serious obstacles to pipeline construction. Adequate routing can be worked out on a regional scale by airphoto interpretation and geological map study where construction would not be unduly hampered or the environment, from a geological-terrain viewpoint, unduly damaged. A more exact routing will require detailed investigations in the area on slope stability, drainage characteristics, thickness and type of organic terrain, distribution of permafrost and ground ice, and engineering properties of the surficial material.

7.2 Area II - South-Central Region: Mackenzie and Liard Rivers,
Martin Hills
(61°10' to 61°50'N Lat.; 119°30' to 123°00'W Long.)

Map Sheets - Southwestern part Mills Lake (85E)
Fort Simpson (95H)
Eastern part Sibbeston Lake (95G)

7.2.1 Overview

Area II (Fig. 2, Map 2) comprises, for the most part, low-lying terrain, generally below an elevation of 1,000 feet that rises gently to the south and has a regional relief of about 500 feet in 50 miles. Toward the northwest, the plain rises more steeply, culminating in the Martin Hills uplands that reach heights of 2,320 feet, with regional relief of about 1,500 feet in 30 miles.

The Mackenzie River flows northwestward through the eastern part of the area. Major northeastward-flowing tributaries include the Liard River, approaching the dimensions of the Mackenzie, Trout River, Jean Marie Creek and the Martin River (Fig. 12).

As indicated in the preceding section, the northern part of Area I is underlain by Upper Devonian limestone. This trend continues into Area II. Terrain at lower elevations is underlain by Upper Devonian rocks whereas the uplands (Martin Hills) consist of Cretaceous sediments. The Devonian rocks form a west-northwest trending belt running north from the boundary with Area I to about the central part of the area where Jean Marie Creek runs east-west. Although consisting mainly of varieties of limestone, rock types include sandstone, siltstone and mudstone. The important factor is that they are relatively resistant and, as will be elaborated upon below, have importance in construction methods and materials. Continuing northward and making up the major portion of the area at lower elevations is the Upper Devonian Fort Simpson Formation. It consists essentially of shale with minor amounts of siltstone, sandstone and limestone. The shale unit of the Fort Simpson Formation is probably the single most important bedrock type in the areas under consideration - it has wide distribution, high erodibility and is a major contributor to the matrix of overlying till. Fort Simpson shale is soft, fissile and contains a high percentage of non-expandable clays (hydromica). Continuing into the uplands in the northwestern part of the area, the Fort Simpson Formation is overlain by the Lower Cretaceous Fort St. John group, consisting mainly of shale, which is in turn overlain by Upper Cretaceous Dunvegan sandstone in the summit areas.

There is a wide variety of surficial deposits in Area II. In the southern area, forming roughly a wedge shape widening to the west, the terrain is covered by till deposits with an average thickness of over

20 feet. The relief is generally low with subdued hummocks and crevasse-filling ridges except in the western part of the area, where east-west drumlinoid ridges are widespread with average local relief of 50 feet. North of this area, there is a belt of gravel and sand about 6 miles wide in the east and narrower westward to one or two miles wide near the Liard River. These sediments, which are partly outwash gravels and partly beach deposits, form northwest-southeast ridges. Generally, the deposits are relatively thin and directly overlie limestone bedrock. North of this belt, forming a triangle between the Mackenzie River and the southeastern slopes of the Martin Hills, are widespread glaciolacustrine silt and eolian sand. The silt is generally over 20 feet thick and forms broad plains with low relief controlled principally by the overlying organic matter. Most sandy areas consist of stabilized fields of longitudinal dunes overlying lacustrine silt. The thicknesses of sand vary, exceeding 50 feet in dunes and 20 feet in intervening depressions.

On the northeast side of the Mackenzie River, lacustrine silt and till form a belt adjacent to the river.

Area II is in the Discontinuous Permafrost Zone, with conditions not unlike those of Area I. Inter-dune areas and depressions between till hummocks and ridges support thick organic deposits with permafrost and ground ice close to the surface. Permafrost has not been recorded in well-drained till areas and in sand and gravel deposits. However, ground ice is recorded in lacustrine silt within 4 feet of the surface in the northern part of the area.

7.2.2 Surficial Deposits

7.2.2.1 Till

The till blanket, characterized in the northern part of Area I by clusters of crevasse fillings and bog- and fenland, changes abruptly near the boundary with Area II to east-west trending drumlinoid ridges and flutings, some several miles long. In the southwestern part of the area, they form a belt about eight miles wide. To the north and east, till persists along an east-west belt that swings northward along the western boundary of Area II. Here, the till forms a broad plain with very little pronounced till morphology. Only occasionally are there distinct hummocky areas, clusters of crevasse fillings, or flutings. Major topographic features such as the Martin Hills are a consequence of bedrock stratigraphy and structure.

In the southern part of Area II, till probably reaches thicknesses of 45 feet, based on seismic shot-hole data west of Area II. Deposits thicker than 80 feet and thinner than 2 feet are recorded. The average thickness for the entire area is probably somewhat over 20 feet. Adjacent to creeks in meltwater channels and in depressions,

there may be gravel, sand or silt overlying the till. Generally, these deposits are less than four feet thick but may reach as much as 40 feet in restricted areas. They are not large enough, however, to map conveniently at the scale presented.

Very few grain-size analyses of till are available for this area. The few that are available show that there are roughly equal parts of sand, silt and clay with the coarse fraction (> 4 mm, pebble-size or larger) running in the order of 5%. Increases in the pebble content occur in crevasse fillings and where till overlies substantial areas of gravel.

Organic terrain is widespread on the till of Area II as in Area I. Irregularly shaped patches of varying size, controlled largely by depressions formed by varying till morphology, are common in the southern part. In the western part, organic terrain occurs as small patches which are mapped in the same unit as the till. Here the till morphology is of low relief, and in general the area is better drained.

Bogland and fenland occur both separately and closely associated but it is apparent that, in Area II, bogland is increasing areally over fenland when compared to Area I. The overall thickness of bogland decreases somewhat, averaging about 9 feet in well-developed areas. However, on the summit of the Martin Hills, the organic material is 19 feet thick.

The frost characteristics remain about the same in Area I and Area II. For example, in the southwest part of Area II in well-developed bogs, the depth to permafrost is between 8" and 20" at about the time of the maximum yearly thaw, and the bog is frozen at least to the bottom of the organic matter. The ice content is high in all bog areas running in the order of 60 to 80% by volume. Only one fenland area was studied; this is in the northwestern part of Area II, on the summit of the Martin Hills and is, therefore, atypical. Here the organic matter is 13.7 feet thick and completely unfrozen.

The only permafrost detected in the till is from test hole cores at the base of bogs. Till was frozen to depths of at least three feet, and contained ground ice. The ice was banded and milky with veins 2 to 5 cm thick. Although permafrost and ground ice have not been observed in any other setting in till, adjacent areas, underlain by silt and clay, contain sporadic permafrost and ground ice not necessarily associated with a thick organic cover. As in Area I, permafrost and ground ice may be present below organic matter less than four feet thick.

Characteristics of surface drainage in till are similar to those discussed for Area I. In the western part of Area II, the drainage is generally better integrated than in either the southern part or Area I because of less-pronounced till morphology and the effect of the broad uplands that include the Martin Hills.

7.2.2.2 Lacustrine Sediments

The dominant surface material in Area II consists of lacustrine silt and sand that blanket a large portion of the area north and east of the till plain at elevations below 850 feet. The deposits originated in a proglacial lake that occupied the Mackenzie Valley for a relatively short time during the deglaciation of the area. Beaches are found near the upper limits of the lake in the southern part and along the flanks of the Martin Hills. A delta was formed at the mouth of the ancestral Liard, depositing sand over much of the area between the present-day Liard and the Mackenzie, and in the area west of the Liard in the northern part of the area. Lake sediments consisting of silt and sand cover the remaining areas and are found below the thick blanket of deltaic sands.

The relatively featureless surface of the lake plain is broken in places by sand dunes that formed after the lake drained. These dunes cover large areas, are prominent in the northern part of the area and, although there are numerous exceptions, are mostly longitudinal, oriented toward the northwest. They are variable in height, some exceeding 50 feet but averaging between 20 and 30 feet. The only other distinctive topographic features in the lacustrine area are peat palsas and peat plateaus.

The lacustrine sediments are generally over 20 feet thick and thin toward the lake margins. On the east side of the Mackenzie, till and lacustrine sediments were not mapped separately due to the difficulty of separating these units at the scale mapped. It appears that there has been non-deposition or erosion of lacustrine sediments in areas known to have been covered by water.

Test holes drilled in a north-south line in the central part of Area II east of the Liard, and observations made along the major rivers, show that by far the dominant near-surface lithologic types are silt and fine sand. It is not easy to generalize on lithologic trends with depth as both an increase and decrease in fine grained sediments occur. Some test holes and sections, apparently in the deeper part of the basin, indicate gravel or till close to the surface. Other test holes show as much as 40% clay and 60% silt and sand. Water content (unfrozen) in clay, silt and fine sand varies between 3% and 49% at various depths. Plastic and liquid limits were taken in one sample of clayey silt yielding 22% and 37%, respectively.

Dunes and other windblown sand deposits vary from fine to medium sand, and are usually very well sorted.

The poor permeability of silt and clay, relatively flat regional terrain, and the deranged nature of the surface of the lacustrine plain have resulted in the widespread occurrence of bogland and fenland both as large tracts and as discontinuous patches. In sand dune areas, one would expect that the sand would drain well enough to retard thick bog and fen development. This apparently does not occur for one or more of the following reasons: 1) enough silt and fine sand have accumulated in the depressions to prevent a high rate of absorption due to low permeabilities; 2) the presence of a high water table; and 3) the presence of ground ice forming an impermeable barrier.

As with till areas, there appears to be an areal increase of bogland over fenland in area II as compared with area I. Peat plateaus and palsas have local relief of as much as twelve feet and are actively degrading in places.

As in other areas underlain by bogland, permafrost and ground ice occur at least to the bottom of the bog. In view of the fact that bogland is widespread over lacustrine areas, permafrost and ground ice are widespread. Permafrost also is present sporadically in areas not necessarily overlain by a thick cover of organic matter. Its presence is difficult to predict, but it occurs in relatively poorly drained areas consisting of clay, silt and fine sand. This eliminates dune ridges composed of sand; hummocks and other positive relief areas composed of fine sand, silt and clay; and sand and coarser grained material in any topographic setting.

In two test holes drilled through two feet of organic matter overlying fine sand, silt and clay, deposits were unfrozen to a depth of at least 20 feet. Three test holes, drilled through organic matter 3.7 feet, 5 feet and 5.5 feet thick overlying clay, silt and sand, showed frozen material below 2 feet, 12 feet and 2 feet, respectively. Fenland in the order of 10 feet thick is unfrozen to at least 20 feet whereas bogland over six feet thick is generally frozen to over 20 feet although in one hole very fine sand was unfrozen from 14.5 feet to the bottom of the hole at 22 feet. In one test hole in unfrozen organic matter the water content is 65% at 3 feet and 112.9% at 6 feet whereas in another test hole in frozen organic material water content was 586.0% at 4 feet and 28% at 6 feet. Water content of several samples at various depths from several test holes that penetrated frozen sediments (fine sand, silt and clay) varied between 11% and 127.1%.

Surface drainage characteristics depend on numerous factors. Much of the area is covered by high porosity - nonpermeable sediments, broad flat areas with subdued surface morphology forming a deranged and poorly integrated drainage system, and bog and fenland areas with

the presence or absence of ground ice. Most of these factors retard surface runoff in the spring and at times of intense rains. There is a high rate of runoff in the local elevated areas but the water collects in numerous nearby depressions. In June and early July, the entire area appears as one gigantic swamp.

In the dune areas, the dunes themselves drain freely and are often dry for much of the summer season although adjacent to the ridges, the drainage is impeded and deranged.

7.2.2.3 Other Deposits

Till and lacustrine sediments are by far the most widespread deposits in Area II. However, beach deposits and glacial fluvial deposits, occurring as broad plains and in abandoned meltwater channels, deserve comment.

Well-developed parallel beach ridges occur as a northwest trending belt in the southern part of the area along the upper margins (to elevation of about 850 feet) of the glacial lake that deposited the sediments described above. The belt exceeds four miles in width with distinct ridges up to about six feet in height and slopes of up to 6°. Toward the northeast, near the Liard River, they become less distinct, having been modified by wind erosion. North of the main belt, toward the deeper part of the basin, isolated, poorly developed ridges can be detected.

The lithology of the beach ridges varies widely depending on the history of development. The best-developed beaches are the highest in elevation and consist of well-sorted, interbedded sand and gravel, up to six feet thick, overlying carbonate bedrock. Toward the northwest part of the area, the belt consists largely of sand, forming beaches of various thicknesses and degrees of sorting. In the deeper part of the basin to the north, the beaches are not as well developed and consist of thin, poorly sorted gravel.

The coarseness of the material ensures little or no ground ice and a high absorption capacity inhibiting surface runoff. The intervening depressions, which contain fine-grained material, support minor areas of bog- and fenland with ground ice probably present in the sub-bog sediments.

The only large scale occurrences of glacial-fluvial gravel and sand are found just south of the beach ridges, in the eastern part of Area II. These form an irregular belt two to three miles wide and 25 miles long. They are well drained, contain no permafrost and ground ice, and vary in thickness, averaging approximately five feet.

Abandoned meltwater channels are widespread in the southern part of the area. They are confined generally to the till and beach areas, forming sinuous patterns but in an overall northwestward direction. They form low, steep scarps with relatively wide troughs, floored by variable thicknesses of gravel and/or sand.

7.2.3 River Crossings

Five major rivers flow through Area II. These include the Mackenzie, Liard, Poplar, and Martin Rivers and Jean Marie Creek.

7.2.3.1 Mackenzie River

In Area II the Mackenzie River has incised through drift, except near Fort Simpson where it has cut below drift into shale.

Scarps near Fort Simpson reach heights of up to 200 feet but decrease up-river toward the eastern boundary of Area II where essentially no scarps are present.

The river follows a relatively straight course with little sign of meandering since its inception following deglaciation. This is confirmed by a paucity of meander scars, point bar deposits and the fact that some islands within the present-day course of the Mackenzie consist of glacial deposits. With minor exceptions, its banks consist of glacial drift, mostly till and fine-grained lacustrine sediments. The Mackenzie essentially separates the area of thick, fine-grained lacustrine sediments in the south from till, or lacustrine sediments over till in the north. Only in the northeastern part of the area is there a series of intermediate terraces between the level of glacial drift and the present river level. There appears to be a minimum amount of deposition associated with the down-cutting. The surfaces have been scoured, exposing till, lake sediment or lag gravels. There are, however, remnants of terraces that contain thick gravels and sand, usually with overlying silt, at various locations along this segment.

If a pipeline is to be buried below the Mackenzie, well-drained till will make the best approach sites. One foreseeable problem is bank erosion caused by high water and ice during spring break-up that may expose and damage the line. Very little is known about river bed conditions. If a suspended pipeline is constructed over the Mackenzie River, the height of the scarp and character of material will constitute the major engineering considerations. With the exception of the intermediate terraces, the scarps increase in height down-river toward Fort Simpson as do occurrences of coarser stratified sediments and till. The till will make a suitable foundation material. When dry, it is hard, compact and relatively well cemented. In selecting a site, the river should be relatively narrow and the scarp high enough both to ensure good drainage and to avoid high flood water with accompanying ice that may occur during spring break-up. Abnormally high water caused by ice damming may bring waters up to 30 feet above normal low water.

Such an occurrence took place in May, 1972, when much of Fort Simpson was inundated causing damage not only by flooding but by the piling and shoving of rafted ice.

On the spot investigation with the aid of the surficial geological map will be necessary for specific location of the pipeline crossing, which should probably be located in the northeastern section of the area.

7.2.3.2 Liard River

The Liard River flows into the Mackenzie near Fort Simpson. As with the Mackenzie River, the Liard has meandered very little since its present configuration was established just after deglaciation of the area. However, as contrasted to the Mackenzie, it has incised to a much greater degree in response to the lower base level of the Mackenzie. Bluffs are in the order of 300 feet high in the southern part decreasing to about 150 feet near the confluence with the Mackenzie. The upper part of the river has cut through thick drift deposits and bedrock. The glacial deposits comprise till and fine-grained lacustrine deposits, generally not differentiated at the scale mapped. In the southern part, the bedrock is formed of gently dipping, resistant sandstone, siltstone and limestone, whereas toward the north, poorly resistant shale is present. Progressing downstream, the river dissects only glacial drift, mainly lacustrine silt and sand, with some overlying windblown material. As on the Mackenzie River, there are remnants of intermediate terraces consisting of sand and gravel.

The high scarps and erosive action of the Liard will be the major problem in burying a pipeline. Spring break-up with high water and ice may cause bank erosion that could expose and damage the line. One positive aspect is the relative stability of the bedrock located in the southern part and below water level. Little information is available on river bed conditions but river bed erosion is expected to be more severe than in the Mackenzie. The best prospects for a suspended pipeline crossing are in the southern part, where till overlies sandstone or limestone, there are well-drained bluffs above high flood level, and where the river is relatively narrow. Large landslide scars occur in bedrock and surficial material at a few locations along the Liard; because they are rare they are not a serious hazard.

7.2.3.3 Jean Marie Creek

Jean Marie Creek flows in an irregular pattern between the Liard and Mackenzie Rivers, eventually entering the Mackenzie in the east-central part of Area II. The upper part of the Creek (southern part of the area) flows northward within an abandoned meltwater channel and then eastward in its own valley. Where it is confined to the meltwater channel, scarps reach heights of over 150 feet but are generally much lower. Resistant limestone is exposed under till in the southernmost part, whereas sandstone, underlying fine-grained lacustrine sediments,

crops out where the creek shifts to the east. The creek meanders only in certain stretches and has banks only a few feet high consisting of silt over coarser sediments.

Where Jean Marie Creek flows eastward in its own valley, it has incised into the lacustrine plain, meandering in a narrow belt and eroding its banks to form scarps with average heights of 10 to 20 feet. Poorly resistant shale is exposed beneath lacustrine silt where the creek once again shifts to the north.

Probably the best location for a crossing would be where the creek flows to the east. The banks are low and one does not have to contend with the abandoned meltwater channel. A major hazard would be the lateral undercutting of banks and therefore a routing should be selected where the river is not actively meandering. Another hazard is the poor engineering performance of silt which is the most abundant surficial deposit in the area. There is also the possibility of ground ice occurring within silt with the possibility of slumping upon thawing or frost action upon freezing. It will be necessary, therefore, to investigate crossing areas carefully in order to avoid ground ice and to locate coarser materials if possible.

7.2.3.4 Poplar River

The Poplar River flows in the southwest part of Area II into the Liard River. As with Jean Marie Creek, the upper reaches flow within an abandoned meltwater channel and its characteristics are not much different from those of Jean Marie. The meltwater channel here, however, has not incised as deeply and is entirely in surficial material, mostly till, with various amounts of associated silt, sand and gravel. The channel scarps are generally less than 50 feet high. The lower portion dissects mostly till with associated silt, sand and gravel, forming scarps 10 to 30 feet in height. Near its confluence with the Liard, the river has cut deeply, forming scarps over 100 feet high and exposing limestone underlying till and discontinuous patches of silt, sand or gravel.

Once again, assuming a pipeline buried beneath the bed, the river offers relatively few obstacles. An adequate crossing with minimal difficulties can be selected in most places with the exception of the high scarps of the meltwater channel in the upper reaches and near the river's mouth. The till offers no serious problems as long as it is well drained. A section of the river should be chosen where there is a minimum of lateral erosion.

7.2.3.5 Martin River

The Martin River flows northward from near the base of the Martin Hills into the Mackenzie River. Its upper reaches follow around the southern part of the Martin Hills incising into a till plain and then northeastward incising into lacustrine silt and sand. The river has formed a relatively wide, dense meander belt. Within the floodplain, the river is laterally migrating, leaving abandoned stream channels and oxbow lakes. Most associated deposits are fine grained, including clay, silt and sand, but gravel is found within the floodplain where the river dissects the till plain. The river scarps vary in height, increasing downstream from around 20 feet to over 100 feet.

It will be necessary to choose a pipeline crossing where the river is not actively undercutting its bank. The best conditions are met in the upper reaches of the river where the banks are low, the floodplain contains gravel and the approaches consist of till. However, careful investigation along the entire river, with perhaps the exception of the lower part, should reveal adequate crossings.

7.2.3.6 Trout River

The lower part of the Trout River is present in the southeast corner of Area II. Here the river has incised through resistant bedrock, mostly limestone, that underlies substantial amounts of silt, sand and gravel, forming banks in places over 100 feet high.

7.2.4 Pipeline Construction Problems

Probably the most significant factors in Area II that will adversely affect the construction of pipelines from a geological-terrain point of view are: 1) bogland, fenland, and the development of both in close association; 2) bogland that is actively degrading at the present time; 3) silt and fine sand which are subject to mass wasting and seasonal frost heaving; 4) ground ice in lacustrine sediments; and 5) river and abandoned meltwater channels. The hazardous nature of these is explained in the discussion of Area I. It should be mentioned that the failure potential of the lacustrine silt and fine sand is greater than that of the till. This includes both mass wasting and seasonal frost problems.

In selecting the best general routing through Area II, one must consider not only the best terrain factors but also where the best routing enters from Area I. The best general routing from Area I is through the area of till between Jean Marie Creek and the lower segment of the Poplar River. This not only avoids crossing Jean Marie Creek but also crosses a more preferable part of the Poplar and leads to one of the better segments for crossing the Liard.

In this portion of the Liard, well-drained till and fine-grained lacustrine sediments overlies resistant limestone, sandstone and siltstone. It should be possible to locate a site consisting of till over resistant bedrock. Crossing the river here leads into an area of till and lacustrine sediments with large tracts of organic terrain that extend to the Martin River. This is not the best material for construction, but is still better as a whole than other possible routes. An intensive on-ground investigation for the best specific location in this area will be necessary. This leads to a relatively suitable crossing of the Martin River. Continuing along the southwestern flank of the Martin Hills, the terrain improves considerably. Here it is composed mainly of till, parts of which are on relatively well drained gentle slopes which will probably not initiate mass wasting if the routing is located carefully. In the northwestern part of the area, it should be possible to locate a line along a well-drained drumlinoid ridge.

7.2.5 Views and Comments

The construction problems in Area II are outlined above. There are, however, routings through the area where satisfactory terrain conditions exist. One satisfactory routing is proposed above, but other equally acceptable routes can be located with the aid of the surficial geology maps. In both cases, further investigations of surface drainage, engineering properties of materials, thickness and type of organic terrain, distribution of permafrost and ground ice and slope stability will be necessary.

7.3 Area III - North-central Region: Mackenzie River Valley (61°10' to 62°20'N Lat.; 120°50' to 123°35'W Long.)

Map Sheets - Northern part Fort Simpson (95H)
Northeastern part Sibbeston Lake (95G)
Southern part Camsell Bend (95J)
Southwestern part Bulmer Lake (95I)

7.3.1 Overview

Area III comprises a northwest-southeast portion of the Mackenzie River Valley (Fig. 2, Map III). It forms a broad valley bordered by subdued uplands - the Ebbutt Hills to the north and the Martin Hills to the south (Fig. 13). The regional relief, extending north and south from the river to the higher parts of the uplands, is about 1,500 feet in 15 miles. The highest elevations of the Ebbutt and Martin Hills in Area III is about 2,000 feet. Many minor streams flow off these uplands into the Mackenzie River, generally cutting through surficial deposits and meandering for most of their courses.

Two major tributaries, the Martin and North Nahanni Rivers, enter the Mackenzie from the south near the eastern end and the western part of the area, respectively.

The extreme western part of the area consists of the northern end of the Nahanni Range and southeastern edge of the Camsell Range, both part of the Franklin Mountains. These are rugged, narrow north-south trending ranges with elevations of over 4,000 feet and local relief in the order of 3,500 feet (Fig. 14).

The broad Mackenzie Valley is underlain by Upper Devonian Fort Simpson shale and siltstone, the highly erodible material discussed in the section on Area II. Toward the west, limestone, shale and siltstone of other Paleozoic formations crop out in a few places. Away from the river, as the uplands are approached, the Lower Cretaceous Fort St. John Group underlies the surficial deposits. As discussed in the section on Area I, the Fort St. John Group contains a high percentage of erodible shale. Toward the west, the highly folded Camsell and Nahanni Ranges, expose several Devonian and older rock formations consisting mostly of limestone, dolomite, shale and lesser amounts of sandstone and siltstone. From an engineering standpoint, the limestone and dolomite are stable, whereas the shale, partly because it is steeply dipping and forms major ridges, is subject to failure.

The surficial deposits can be separated into three major groups: lacustrine sand and silt, till, and fluvial deposits - glacial and post-glacial silt, sand and gravel.

Lacustrine silt and sand are found in a belt in the lower part of the valley paralleling the river. These deposits, which may be over 50 feet thick, pinch out to the north and south onto till. In the western part of the area, lacustrine silts are found to the base of the Camsell and Nahanni Ranges.

Till, forming typical morphology, is found on the flanks and summit area of the uplands. In the mountain areas, till has been eroded, exposing bedrock with colluvial deposits found at the bases of slopes.

Extensive fluvial deposits are found in the floodplains of the North Nahanni and occasionally in terraces and floodplains of the Mackenzie.

Area III is still in the Discontinuous Permafrost Zone, but zones of permafrost increase and are made obvious through the presence of ground ice. This area is farther north, with relatively high elevation in some parts. Ground ice is common because of the widespread occurrence of organic terrain and the fine-textured nature of the till and lacustrine deposits.

7.3.2 Surficial Deposits

7.3.2.1 Till

The most widespread surficial deposit in Area III is till, which, for the most part, forms a broad plain on either side of the Mackenzie River except along the lower part of the valley and in the mountainous areas to the west. A variety of till features are present including hummocks, drumlinoid ridges and flutings, and crevasse fillings found mostly in the southern part. Seismic shot hole data and test holes indicate that the till is at least 40 feet thick in places, but the average is probably somewhat less.

The texture and lithology of the till is much the same as that found to the south, deposited by the same ice sheet and, for the most part, over the same type of terrain and bedrock. Test data from three holes on the north side of the Mackenzie in the north-central part of the area indicate that the matrix consists of silt, clay and sand in roughly equal amounts but with silt somewhat more abundant. The coarse fraction (> 4 mm pebble-size or larger) averages about 5 to 10%, although locally near the surface it may run as high as 30%. Two test holes drilled to depths of 22 feet in unfrozen till indicated water contents varying between 10% and 23%.

Crevasse fillings found in the southern part of the area consist of moderately sorted gravel and form ridges usually less than three feet high. This contrasts with other areas where crevasse fillings consist of coarse till or extremely poorly sorted gravels.

Organic terrain overlying till is distributed in much the same way as in Area II and thicknesses are about the same. There is usually more bogland although fenland areas and ponds are widespread. Data from one test hole in the north-central part of the area show 15 feet of frozen bogland over lacustrine clay, silt and sand. The average organic thickness in areas mapped as either bogland or fenland is less, averaging something between 6 and 9 feet.

As in other areas described, permafrost and ground ice always are present in bogland, usually penetrating well into the underlying surficial material. Fenland and pond areas usually are free of permafrost, as are well-drained hummocky ridges and mounds. Moderately well or poorly drained till underlying less than four feet of organic matter may or may not contain permafrost and ground ice. Two examples can be cited from the north-central part of the area. Till on a moderately well drained area with less than 1/2 foot of organic matter contained no permafrost for at least 22 feet. Till, 17 feet thick, underlying 5 feet of clayey silt and 2 feet of unfrozen organic matter was frozen for its entire depth but contained no visible ice.

Where permafrost does occur either below thick bogland overlying till, or where the organic cover is less, the depth of the active layer varies between about 8 inches and 2 feet. This is not unlike the situation to the south and, as will be seen, to the north.

Surface runoff during spring thaw and intensive rains is rapid because the till lies for the most part on gentle slopes dipping toward the Mackenzie and has local areas of positive relief such as hummocks and ridges. The runoff is enhanced by the low permeability of the till and, in the spring, by seasonal frost near the surface. In poorly drained areas, such as depressions between hummocks and ridges that do not support permafrost, there is little runoff but a high moisture content because of the high absorption capacity of the till and organic matter. In the same situation where there are thick deposits of frozen bogland, surface absorption may be very slow, and the impermeable ground ice may cause local ponding.

7.3.2.2 Lacustrine Sediments

The lacustrine sediments that were prevalent in the northern part of Area II continue down the Mackenzie Valley into Area III. Here they are present in a belt on either side of the river and adjacent to the mountains at the west end of the area. The boundaries between till and lacustrine sediments often are difficult to define because of thinning of the lacustrine sediments over till. The lacustrine sediments essentially form a wedge, thinning away from the river into discontinuous patches. In the west, adjacent to the mountains, there is a more uniform thickness of lacustrine sediments ending abruptly along the base of the mountains.

The surface of the lacustrine sediments forms a relatively flat plain with deranged drainage caused by small-scale variations in the relief of the sediments and organic terrain. In the east and central part of the area drainage is fairly well integrated due to a slight slope of the surface toward the Mackenzie. Toward the west, where drainage is poorer, there are wide areas of bogland pitted with thousands of small lakes. In these areas, thermokarst lakes are forming at the present time, characterized by steep collapse scarps with heights up to 5 or 6 feet, supporting "drunken" trees.

Thicknesses of the lacustrine sediments varies, but is predictable to a certain extent by the wedge shape of the deposits. Near the Mackenzie River, over 90 feet of lacustrine sediments are encountered occasionally. Seismic shot holes and test drill holes in the thicker deposits indicate 15 to 30 feet of lacustrine sediments thinning to the south and north. Thicknesses vary according to local topography but areas of less than four feet are extensive. Little information is available on the area toward the west near the mountains, but two outcrops had lacustrine deposits 20 and 40 feet thick.

The grain size of the lacustrine sediments varies a great deal, consisting of various amounts of clay, silt and sand with a general tendency for a decrease in grain size with depth. Coarser material near the surface may be in part fluvial sediments deposited in the incipient stages of the formation of the present-day Mackenzie River.

Thick organic deposits are not widespread on the gentle slope adjacent to the Mackenzie. Probably the most widespread occurrence is in poorly drained areas northwest of Fort Simpson and in the western part of the area adjacent to the mountains. As previously indicated, large areas of bogland, some degrading, are present. In these areas, the depth to permafrost is less than two feet in bogs and deeper than nine feet, if present at all, below ponds, fen or transitional areas. In bogs, the moisture content is very high with a value obtained from a sample at 3 feet in one test hole of 1,340% by weight. The average thickness of organic terrain is between 6 and 9 feet. As with the till, permafrost present in bogs continues well into the underlying lacustrine sediments. In one test hole, 13 feet of frozen bog overlies at least 15 feet of sandy, clayey silt. Ice crystals were common in the sediments with moisture content of 67% at 21 feet and 28% at 26 feet.

Observation of outcrops along the Mackenzie River and test-drilling information indicate that large volumes of ground ice are present, discontinuously in fine-grained sediments and not necessarily overlain by thick organic deposits. The occurrences are difficult to predict but are more widespread than in lacustrine areas to the south and in associated till deposits. Therefore, ground ice may be present below poorly drained areas with less than four feet of organic matter and occasionally is present below about five or six feet in fairly well drained areas with dense spruce forests. Examples of the latter can be observed along the banks of the Mackenzie below Fort Simpson where retrogressive thaw-flow slides have exposed at least six ice-rich sections (Figs. 15, 16, 17, 18). About two miles northwest of Fort Simpson, 6 to 10 feet below the surface, there is an ice lens, 10 feet thick, interbedded in clayey silt. Only drilling will reveal how commonly and under what conditions ground ice will occur.

Where the broad terrain is relatively flat, surface runoff is locally high off ridges and hummocks. Intervening depressions retain moisture, commonly manifested by ponds, because of the poor permeability of lacustrine sand, silt and clay, the deranged drainage pattern, and the poor permeability of frozen zones. Where the terrain is sloping with an integrated drainage system, surface runoff may be high during spring melting and intensive rains for one or more of the following reasons: 1) poor permeability of lacustrine sediments, 2) frost close to the surface, and 3) massive ground ice near the surface.

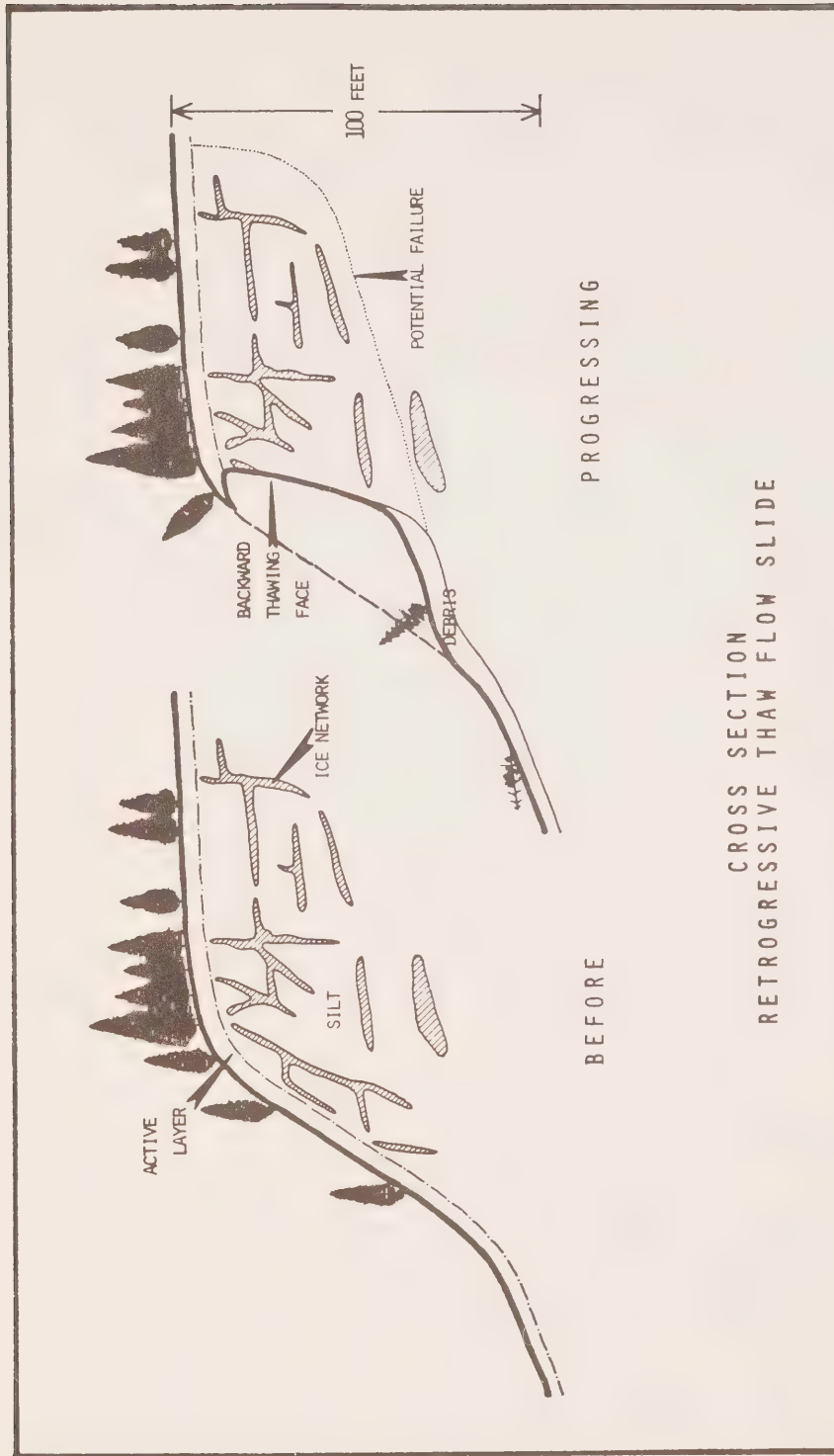


Figure 15. Stylized cross-section of a simple retrogressive thaw flow slide. If ice-rich, fine grained sediments are exposed on a slope, the face will thaw back producing a slurry on the floor. Erosion will continue until the floor dissects the surface or the sediment contains no more ice. This type of failure is common in lacustrine silt and clay and till in permafrost areas.

7.3.2.3 Glacial and Post-Glacial Fluvial Sediments

The only other widespread deposits in Area III consist of fluvial gravel and sand present in the terraces and floodplain of the North Nahanni River, the major abandoned meltwater channels in the southwest part of the area, and occasionally in terraces and the floodplain of the Mackenzie River.

Sections of gravel and sand are variable in thickness from a few feet to over 50 feet in the higher terraces. Individual beds of gravel or sand vary from several feet to a few inches. The terrain usually is well drained with little surface runoff and no ground ice or thick overlying organic deposits.

Special mention should be made of terraces found along either side of the Mackenzie. Gravel deposits have been found near the surface in a few locations near Fort Simpson, and below thick, fine-grained sediments in isolated locations between Fort Simpson and Camsell Bend. Generally, however, terraces including abandoned channels, consist of fine-grained sediments mostly silt and sand near the surface and to depths of at least 20 feet as revealed by exposed scarps along the river. Poorly drained areas such as abandoned channels may have overlying bog- and fenland. Frost and lithologic characteristics are the same as those described for lacustrine sediments and, indeed, in most cases are part of the lacustrine unit, only now below a terrace or channel formed by fluvial erosion.

7.3.3 River Crossings

Three major rivers flow across parts of Area III - the Martin, Mackenzie and North Nahanni. Each have different characteristics that may affect pipeline construction.

7.3.3.1 Mackenzie River

When viewing pipeline routes on the whole in the Mackenzie Valley, it becomes apparent that, no matter what the specific route might be, the chances are it or they will cross the Mackenzie somewhere between Camsell Bend and Fort Simpson. Unfortunately, much of the terrain bordering the river is poor for foundations or approaches.

As previously discussed, the Mackenzie dissects an old lake basin, formed when the lake drained soon after deglaciation of the area. Since its inception, the river has meandered very little. Banks vary in height, controlled principally by whether it is cutting directly into the lake plain, where scarps can be over 200 feet high, in terraces or old channels, or flowing past islands and bars of its own floodplain where scarps may only be a few feet high.

Bedrock is exposed only near Fort Simpson on the north and south side of the river where soft shale is found below thick surficial deposits, and 10 miles southeast of the North Nahanni River on the south side of the river where resistant limestone crops out.

A crossing along this segment will depend largely on the texture of the sediment, river width, drainage characteristics, and presence or absence of ground ice. With proper investigation, fairly well drained sites with little or no ground ice and a reasonable river width can be located. The terrain material will be a problem as most is composed of fine sand, silt and clay with poor engineering properties. Thick, fairly well drained, ice free sand deposits are present along the north side of the river at the eastern end of the area, however, the performance of sand is variable. The opposite bank consists of fine-grained material, and the river is not particularly narrow. The resistant limestone located near the west end of the area forms a ridge to the river's edge and would make an ideal location for a bridge foundation. However, the river is relatively wide here and the opposite bank is not particularly suitable.

7.3.3.2 North Nahanni River

The North Nahanni River, located at the western end of Area III, is the first major river encountered flowing from the Mackenzie Mountains. It is braided, resulting from differential discharge, and the floodplain is up to two miles wide with numerous bars and channels composed of sand and gravel. At the present time, the active channels are located near the east side of the floodplain, eroding alluvial fans, gravel and sand terraces, lacustrine silt and clay, and floodplain deposits. Banks vary in height from a few feet to over 80 feet.

Special construction problems will be encountered in burying a pipeline below a braided river. Probably the biggest problem in construction planning is predicting the hydrologic regimen and resultant changes in channel morphology. Channels shift regularly, therefore aggrading in one place and downcutting in others. Banks are subject to a high rate of erosion, often unpredictable. Thus, a buried pipeline is subject to undercutting and damage both in the river bed and banks. If a pipeline is suspended, adequate crossings can be found but the great width of the North Nahanni will probably rule suspension out.

7.3.3.3 Martin River

The lower part of the Martin River flows into the Mackenzie near the southeast corner of Area III. The characteristics of this river were discussed under Area II and are relatively unchanged in Area III. Here, the river meanders with somewhat higher banks, composed of

lacustrine silt and clay that may contain ground ice. The big problems, therefore, are the approaches. The banks are subject to rotational shear and retrogressive thaw-flow slides, both in their natural state and, if disturbed, during construction. A warm line will melt ground ice if present, perhaps causing collapse of the line, and a frozen line may buckle, by freezing indigenous moisture in the fill.

7.3.4 Pipeline Construction Problems

Probably the greatest problems during pipeline construction will be encountered in: 1) areas of thick organic matter consisting of unfrozen fenland and ice-rich bogland; 2) bogland that is actively degrading at the present time; 3) fine-grained lacustrine sediments consisting of fine sand, silt and clay which are subject to failure and frost heaving; 4) ground ice that may be difficult to predict in fine-grained sediments; and 5) the selection of suitable river crossings. However, with careful planning, field observations and test drilling, an adequate route should be located.

Considering preference shown by industry and in highway location, the routing suggested in Area II, and the most desirable terrain in Area III, the following routing is suggested. Area III is entered north of the Martin Hills, passing through well-drained, ice-free flutings striking northwestward, and then a broad plain of fairly well drained till consisting of a network of low relief crevasse fillings composed mainly of poorly sorted gravels. The topography is such that some bogland will be encountered but not enough to cause a major hazard. Next, the routing passes north through a broad, fairly well drained till plain where little ice is to be expected. As the Mackenzie is approached, fine-grained lacustrine sediments will be encountered. These become thicker toward the river and may contain sporadic ground ice below depths of about 5 feet. On the north side of the Mackenzie (see section on river crossings), terraces and old stream channels consisting of thin, fine-grained lacustrine deposits over till, and till are present at the surface. The fine-grained sediments have the same characteristics as those found on the south side. In the centre of the proposed corridor on the north side is an area of fenland and bogland - some actively degrading - that should be avoided. The selected river crossing will determine on which side of the organic terrain the pipe will run although the east side is better drained and more till will be encountered.

7.3.5 Views and Comments

The major terrain factors that will cause construction problems in Area III have been discussed above. The proposed routing is probably best when considering all geological terrain factors, however,

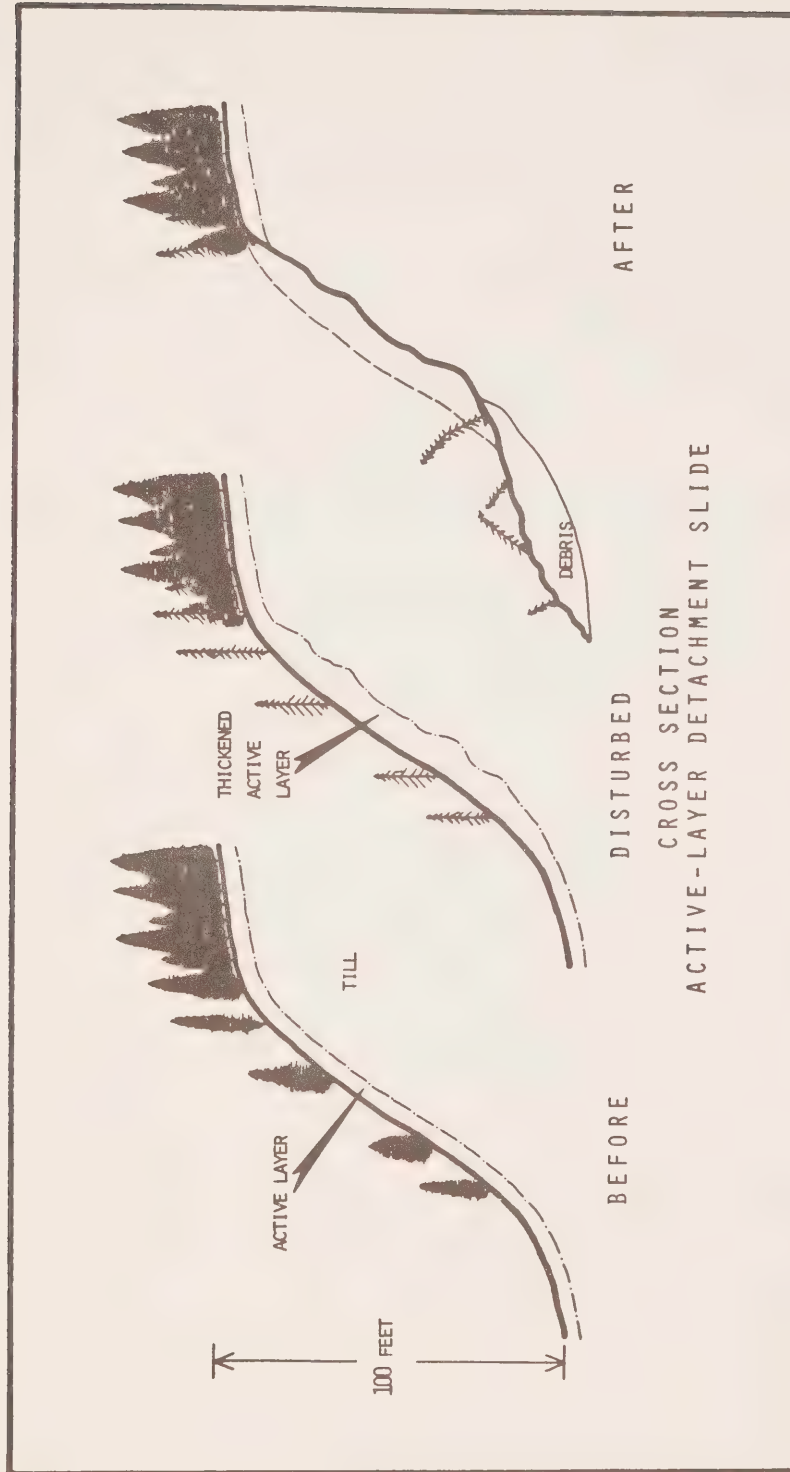


Figure 20. Stylized cross-section of a simple active-layer detachment slide. If thermal penetration thickens the active layer of a saturated slope as a result of fire or man induced activity, the slope may fail. This can occur in fine grained lacustrine sediments, till or poorly resistant shale. In non-permafrost areas, similar failure can occur in saturated sediments overlying impervious material.

adequate routings can be planned throughout this area without encountering prohibitive terrain. If a corridor is planned outside the route proposed, it would be better to select a more easterly route. This is superior to that found to the west where thick, poorly drained, ice-rich, fine-grained lacustrine sediments with overlying organic terrain, some actively degrading, are present. The additional hazard of the braided North Nahanni also would have to be considered.

A more exact route will require more detailed test drilling and field observations to determine the texture and lithology of materials, distribution of permafrost and ground ice, surface drainage and character of organic terrain. Engineering tests and normal laboratory analyses also will be necessary.

7.4 Area IV - Northern Region: Ebbutt Hills - Wrigley (62°20' to 64°00'N Lat.; 121°40' to 124°40'W Long.)

Map Sheets - Southwestern part Bulmer Lake (95I)
Camsell Bend (95J)
Wrigley (95-O)
Eastern part Dahadinni (95N)

7.4.1 Overview

Area IV comprises a roughly wedge-shaped tract of terrain narrowing northward to the limits of the area investigated (Fig. 2, Map 4). Included in this area is part of the Ebbutt Hills and a north-south segment of the Mackenzie River Valley. The river occupies a wide valley bounded on the west by the rugged Mackenzie Mountains and dissected piedmont and on the east by broad uplands (Ebbutt Hills) and the rugged Franklin Mountains (Fig. 19). Local relief varies, but a difference of 3,000 to 4,000 feet between the river and to the bordering mountains, over a distance of only four or five miles, is not uncommon. In the southern part it is much less, running about 1,500 feet in about 35 miles to the summit area of the Ebbutt Hills. A dense, well-integrated drainage network is present. Some streams flow into the Mackenzie off the adjacent mountains, piedmont and uplands and others cut across the mountains from the plains to the east and from mountain ranges to the west.

The highly folded mountains expose a variety of bedrock whereas the uplands and piedmont are underlain by relatively flat-lying, less complex, bedrock. As in other areas discussed, the bedrock consists of two major types - carbonate and shale. Poorly resistant shale underlies the broad valley of the Mackenzie including the piedmont and uplands areas. The shale is mostly Upper Devonian, Fort Simpson Formation and Lower Cretaceous Fort St. John Group. On steep slopes, the shale is subject to active-layer-detachment-slides (Figs. 20, 21, 22). The parts of the Franklin Mountains and the rugged terrain of the Mackenzie Mountains included in Area IV consist mostly of highly resistant dolomite and limestone.

Outcrops of bedrock are confined mainly to the mountains and to banks of the major rivers. Particularly good exposures occur in the deeply dissected piedmont area of the Mackenzie Mountains. Bedrock outcrops are relatively scarce along the Mackenzie, but increase in abundance northward.

It should be mentioned here that two well-known groundwater discharge areas are located just north of Willowlake River near its mouth, and north of Wrigley at the base of Roche-qui-Trempe à l'Eau. These are associated with inactive thrust faults trending northeastward at the base of the eastern flank of the southern tip of the McConnell Range of the Franklin Mountains and the eastern flank of Mt. Gaudet, an outlier of the Franklins.

Surficial deposits, consisting largely of till and lacustrine sediments, are widespread in the lower part of the Mackenzie River Valley, the piedmont area of the Mackenzie Mountains and the upland areas in the southeastern part of the area. The lacustrine sediments are largely fine grained, consisting of silt and clay, whereas the till contains usually less than 5% of pebble-size and larger material (>4 mm) in a matrix containing a high percentage of silt and clay.

Other deposits are areally minor. Coarse glaciofluvial sediments are found principally on the higher terraces along tributaries of the Mackenzie, in abandoned meltwater channels and in widely distributed areas of ice-contact deposits. Post-glacial fluvial sediments are confined to floodplains and low terraces of modern streams. The mountains are relatively free of surficial material. Colluvium, including talus cones, and alluvial and rock fans are found at the base of steep slopes and mouths of mountain streams.

Probably the most important terrain factor of Area IV when considering pipeline construction and related activities is the distribution of permafrost. There is a marked increase in depth, thickness and distribution northward. This is apparent by the increase of ground ice in till and fine-grained lacustrine sediments with less than four feet of organic covering. Somewhere north of the Willowlake River, permafrost becomes essentially continuous in fine-grained materials. This can be stated with certainty only where permafrost is apparent by the presence of ground ice, which may be in the form of disseminated particles, seams, reticulated networks, wedges or tabular bodies.

In the higher mountain valleys to the west of Area IV, permafrost and ground ice are widespread in all surficial materials. This is the first area that ice was observed in gravel, exposed in banks of actively meandering streams (Fig. 23).

Area IV contains numerous Mackenzie River tributaries, many of which will have to be crossed if a pipeline is constructed in this area. Those that will be discussed include the Root, Willowlake, Wrigley, Ochre, Johnson, Blackwater and Dahadinni Rivers and the River Between Two Mountains.

7.4.2 Surficial Deposits

7.4.2.1 Till

Till deposits are widespread in the uplands of the southern part of the area, the piedmont area in the north, and along the Mackenzie Valley bottom with the exception of the west and east side of the river in the southwestern corner and the east side of the river in the northern part. Generally, the surface morphology is rather subdued with broad hummocks and depressions having relief of only a few feet. The major exception to this is the presence of drumlinoid ridges and flutings in scattered areas, principally in the north. On the east side of the river in the southern part, they trend generally in a west-northwesterly direction. In the north, along the Mackenzie Valley, they have a more northerly component.

Till thicknesses vary, with the greatest depths recorded along the river valley and the lower parts of the uplands in the southern part of the area. Till over 65 feet thick has been recorded in the uplands and 80 feet in the river valley near Wrigley (Fig. 24), however, seismic data indicate an average thickness of between 20 and 30 feet. In the piedmont area west of the Mackenzie, thicknesses are generally less, on the order of four or five feet. It is often difficult to distinguish the contact between the till and the underlying bedrock because of the similarity in texture and hardness.

Although there are variations, the matrix of the till has roughly equal parts of sand, silt and clay. Inclusions (> 4 mm, pebble-size or larger) account for usually less than 5% of the total volume. As mentioned above, the till matrix strongly reflects the lithology of the shale. The resistant carbonate, forming the mountains of the area, is reflected in the till by a calcareous matrix and an occasional inclusion. Most inclusions, however, are derived from the igneous and metamorphic terrain of the Canadian Shield. Four test holes indicate that the moisture content of 9 samples varies between 12% and 18% in the upper 22 feet of unfrozen till. In frozen till, 42 samples from 12 test holes indicate that the moisture content varies between 6% and 59% in the upper 22 feet of till.

Organic terrain is found overlying till in relatively flat, poorly drained areas. Most commonly it is located in the uplands area in the southern part and adjacent to the Willowlake River and the west side of the Mackenzie in the central and northern part. Except for a limited amount of fenland in the south, over 90% of

the organic terrain is bogland. Thicknesses vary but are generally between 6 and 9 feet. Peat polygons are found commonly in Area IV along the base of the east side of the Franklin Mountains and in the northern part of the Wrigley map sheet (95-0) (Figs. 25 and 26).

Estimates of the water content have been made in frozen bogland in Area IV from numerous test hole samples. Water content by weight varies between about 95% to 830%, most being in the range of 300% to 400%. As in the other areas discussed, the terrain underlying thick bogland is frozen with a high ground-ice content. Below the bogland, the till is frozen with ground ice present in at least the upper five feet of the unit. Below this, permafrost persists. Exact depths are unknown, but they probably increase northward and at higher elevations.

In areas where the organic cover is less than four feet thick, permafrost is sporadic. As mentioned above, north of the Willowlake River the permafrost cover is almost continuous, with ground ice forming disseminated particles, lenses, seams, reticulated networks and tabular bodies (Fig. 27). The depth to permafrost, if present, varies between about one to eight feet, and permafrost extends to at least 22 feet, the depth of many test holes from which information is available. Outcrops of till near Wrigley contain ice to at least fifty feet.

Surface drainage rate and volume on till, for the most part, depend upon the regional and local topography and on the presence or absence of permafrost near the surface. In the southern part of the area where there may not be permafrost, that is on crests of flutings and drumlinoid ridges or on slopes controlled by bedrock, runoff may be inhibited to a certain extent by absorption into the till. However, in the spring, before the active layer has melted, the rate of runoff will be high and the low permeability of till will promote runoff. In the north, where permafrost is close to the surface in most varieties of terrain, a high rate and volume of runoff will ensue both during spring melting and during intense rains. Runoff will be slow and surface water will stand in relatively flat areas and depressions aided by frozen bogs and deranged drainage.

7.4.2.2 Lacustrine Sediments

Lacustrine sediments are widespread in the southernmost, central and northern parts of the area bordering the Mackenzie River. In the northern part, they are more extensive on the east side where they extend to the base of the Franklin Mountains. In general, the lacustrine sediments form a relatively flat plain with little surface morphology except for overlying organic terrain. Organic terrain, mostly frozen bogland, is widespread, forming irregular hummocks and

water-filled depressions and creating a deranged drainage network. Some of the palsas have local relief up to 17 feet, whereas are actively degrading forming thermokarst lakes.

Lacustrine sediments that make up sizeable map-units are usually over twenty feet thick with some exposed sections and sections from test holes having thicknesses over 100 feet. Data indicate that there are fairly thick deposits right to the limit of the former lake with the exception of the southern area, just east of Camsell Bend, where thin lacustrine sediments (mostly < 4 feet thick) overlying till extend northward in a depression between two uplands.

Although variable, the upper 5 to 10 feet of lacustrine sediments are generally coarser than those below; typically fine sand and silt overlying silt and clay. In the southern part, adjacent to the west side of the Mackenzie River, fine to medium sand is present and appears to form a facies change with finer material to the west, although these coarse deposits may be in part fluvial, deposited just after the lake drained.

Extensive drill hole data are available from the east side of the Mackenzie River in the central and northern areas whereas only sparse information is available in the south. In the central and northern areas, numerous samples from several test holes indicate frozen silt and clay have a moisture content varying between about 8% and 349% and sand between 25% and 35% in at least the upper 26 feet. Plastic and liquid limits vary between 18% and 40% and between 32% and 60% respectively. In the south, 10 samples from 2 test holes in frozen material indicate moisture content between 20% and 26% in at least the upper 26 feet of sediment.

The most important terrain characteristic of the lacustrine sediments is the wide distribution of permafrost and subsequent ground ice (Fig. 28). As in other areas below extensive deposits of bogland, till or fine-grained lacustrine sediments are frozen and contain ground ice in at least the upper few feet of the deposit.

In the central and northern parts of Area IV, permafrost and ground ice are found extensively in the lacustrine silts in moderately to poorly drained areas without regard to the thickness of the organic cover. About the only place permafrost is not found is in well-drained scarps and below pond and fenland areas. In general, permafrost is found within two feet of the surface and extends to at least 25 feet and probably to 50 feet or more.

In the southern area, permafrost and ground ice is less extensive in lacustrine deposits than in the central and northern parts. Not only is this attributed to lower latitudes, but extensive bogland cover is undergoing active thermokarst subsidence, resulting in permafrost patches between unfrozen ponds and marshes.

The ice is manifested in several ways. Most commonly it occurs:

- 1) disseminated as fine particles within silt, or silt and clay;
- 2) as discrete layers, from a fraction of an inch to about 3/4 of an inch thick, separated by less than an inch to 2 or 3 inches of silt, or silt and clay;
- 3) as lenses up to about 2 feet thick; and
- 4) as a reticulated network of varying thicknesses. The volume of ice present in the upper 10 feet of sediment in the central and northern areas reaches 80%.

In the south, organic terrain over four feet thick is widespread. It is composed largely of bogland forming peat palsas, up to about 15 feet in height, separated by ponds and fenland. As mentioned above, some of the bogland is undergoing thermokarst subsidence. Depth to permafrost is less than two feet and permafrost extends well below the organic matter which varies in thickness between about six and nine feet. In the central and northern areas, organic terrain is not as prevalent when considering the total area of lacustrine sediments. Thermokarst subsidence is not as common and most of the organic material is bogland. The depth to permafrost is less than two feet, and permafrost extends well below the limit of the organic matter which, in well-developed bogs, is a bit less than that found to the south and averaging about five to eight feet.

Surface runoff is retarded in flat-lying lacustrine areas, such as in the south, by the irregular surface and deranged drainage pattern, caused partly by thick organic deposits. Small ponds dot the area in spring with the water level slowly lowering during the summer season. In the central and northern areas, lacustrine sediments generally are better drained than those found farther south. On slopes, the rate and volume of surface runoff is high during spring melting and after intense rains due to the poor permeability and high ice content of the near-surface deposits.

7.4.2.3 Glacial and Post-Glacial Fluvial Sediments

Fluvial deposits, from an areal standpoint, are not widespread in Area IV. They can be divided conveniently into two groups - glacial fluvial and post-glacial fluvial deposits. The former include ice-contact material consisting of crevasse fillings, kames and eskers, outwash deposits exposed mainly in the higher terraces along major rivers, and abandoned meltwater channel deposits. Post-glacial deposits consist of material found in low and intermediate terraces and floodplains of modern rivers and creeks.

The distribution of the glacial fluvial deposits can be seen on the surficial geology maps. Ice-contact deposits are concentrated between the Willowlake River and the River Between Two Mountains on the east side of the Mackenzie River. Here, crevasse fillings,

eskers and kames cover a high percentage of the area. The texture of the deposits is coarse, mostly gravel, or gravel and sand; they are well drained with no permafrost or ground ice and a minimum of organic cover. Thicknesses of the deposits vary between a few feet for crevasse fillings to over 50 feet for kames and eskers although the average is probably in the order to 20 to 30 feet. Outwash is exposed as high-level terraces at various locations bordering the Mackenzie and other major rivers of the area. It consists of gravel, gravel and sand, and sand, commonly overlain by post-glacial silt. Outwash thicknesses vary, but are usually over twenty feet. They are well drained, contain no permafrost or ground ice, and have little overlying organic matter.

Abandoned meltwater channel deposits are present in various locations in Area IV. Portions of channels are located adjacent to the Mackenzie River and the valleys of major rivers. Size varies but, as with most meltwater channels, the width is several times greater than the depth. Deposits consist of variable amounts of sand and gravel or else the channel is floored with material into which the channel was incised. In some meltwater channels, the channel deposits are overlain by silt deposited by floodplains of streams that have occupied the channel since deglaciation. When this occurs, thick organic terrain with peat palsas commonly is present, impeding drainage, promoting permafrost and ground-ice development. If there is little or no overlying silt, there is usually good drainage, only a thin organic cover and no permafrost present.

Post-glacial fluvial deposits occur in low and intermediate terraces and floodplain deposits of modern rivers and creeks. In most terraces, variable thicknesses of gravel and sand are present, commonly overlain by silt. As explained above, the texture of the surface deposits influences the drainage, permafrost distribution, and thickness of organic cover.

Modern floodplains consist of variable amounts of silt, sand and gravel. Coarse material is probably more abundant in the floodplains of rivers flowing into the Mackenzie from the west from deep within the Mackenzie Mountains. With few exceptions, however, the volume of sand and silt is higher than gravel.

In bars and islands of the Mackenzie, the surfaces commonly are covered with pebbles and boulders. This is misleading when predicting the texture of the material below because sand and silt usually are found within a foot of the surface. The pebbles and boulders are lag deposits lodged into the underlying sediments by river ice during breakup.

At higher elevations in the Mackenzie Mountains west of Area IV, gravel and sand contain ground ice exposed by erosion of modern streams.

7.4.2.4 Other deposits

Colluvial deposits consisting of reworked surficial material and bedrock rubble are present at the base of steep slopes. The thickness, texture and sorting are variable; usually there is a thin organic covering and permafrost and ground-ice are present in fine-textured material.

7.4.3 River Crossings

Any pipeline constructed in Area IV will have to cross a number of rivers and streams no matter which side of the Mackenzie is utilized. The major rivers with potential crossings are the Willowlake, Ochre, Blackwater, Root, Wrigley, Johnson, Dahadinni Rivers and the River Between Two Mountains. There are others that are similar in character and need not be discussed.

7.4.3.1 Willowlake River

On the east side of the Mackenzie, Willowlake is the principal river, draining a large area of the plains region to the east. It meanders very little, following the course of an abandoned meltwater channel. The channel is nearly one mile wide and has sides about 100 feet high. Within the channel, fine colluvium, alluvium, and fine-grained lacustrine deposits are present adjacent to the river. The channel dissects a till plain that is fairly well drained. On the north side, drumlinoid ridges, hummocks and crevasse fillings are found toward the west, and subdued hummocks with a high percentage of bogland toward the east.

The fairly well drained till probably does not contain a high percentage of ground ice whereas, within the channel, permafrost and ground ice could be encountered in the more poorly drained, fine-grained sediments.

Shale bedrock is exposed in the lower parts of bluffs at various locations along the channel. The shale is part of the Fort Simpson Formation and therefore extremely unstable.

The approaches to the channel and river consists mostly of till and fine-grained fluvial and lacustrine sediments, whereas coarse- and fine-grained sediments and colluvium are presently within the channel. A pipeline crossing should be located in a well-drained site in order to avoid possible ground ice. Before burying a line beneath the riverbed, more data are needed on the hydrology of the river with respect to erosion or sedimentation. The river is undercutting its banks in only a few locations.

7.4.3.2 River Between Two Mountains

The River Between Two Mountains flows from Fish Lake, on the east side of the Franklin Mountains, across the southern tip of the McConnell Range into the Mackenzie. In its lower path, the part in Area IV, it meanders moderately, cutting through limestone bedrock where it crosses the McConnell Range, a till plain and an alluvial terrace and, towards its mouth, fine-grained lacustrine deposits. Scarps bordering the river are generally less than 50 feet high, fairly well drained but may contain ground ice. The river is shallow, only a few feet in depth, with a narrow floodplain and riverbed of coarse gravel and sand.

For pipeline construction, the approaches to the river should be in ice-free till. Although till is subject to slope failure and frost heaving, it has better performance than lacustrine sediments. River crossings should be selected where the banks are not being undercut by lateral erosion.

7.4.3.3 Ochre River

The Ochre River flows from the Plains through the McConnell Range into the Mackenzie. The Ochre meanders strongly, cutting through till in its upper part, fine-grained lacustrine sediments in the central area and coarse alluvium towards its mouth. The floodplain is close to one-half mile wide forming steep scarps, up to about 100 feet high, mostly in glacial material. The river is shallow with its bed, floodplain, and associated terraces consisting of coarse gravel and sand. The terraces commonly have a few feet of overlying silt. Bedrock crops out only rarely.

In pipeline construction, the approaches to the river may offer problems. Exposure of lacustrine silt and clay, and till during pipeline burial near and within the scarp probably would initiate retrogressive thaw-flow slides, thermokarst subsidence and gully erosion. Once the line is buried, collapse and flexure may result if the line is warm, and frost heaving if the line is cold. The gravel and sand terrace near the Mackenzie is ice-free with little or no permafrost.

The riverbed, floodplain and lower terraces should offer few problems during construction, and crossings should be located at sites free of lateral erosion.

7.4.3.4 Blackwater River

The Blackwater River originates well in the plains area on the east side of the Franklin Mountains and flows westward into Blackwater

Lake. It then cuts across the Franklin Mountains and into the Mackenzie. Area IV includes only the lower part of the river where it crosses the Mackenzie Valley. The river meanders moderately, passing through a floodplain up to 1/2 mile wide with low alluvial terraces that abut against scarps of fine-grained lacustrine sediments, some up to 300 feet high. Only near the mouth does the river erode against terraces consisting of glacial or post-glacial gravel and sand.

As with the Ochre River area, the scarps enclosing the floodplain and lower terraces may fail when disturbed during construction. The lacustrine silt is frozen, commonly with a high percentage of ground ice. The alluvium near the mouth should offer few problems as this material is generally coarse with essentially no ground ice. Once again, a crossing should be selected where the river is not laterally eroding.

7.4.3.5 Dahadinni River

Crossing west of the Mackenzie, opposite the mouth of the Blackwater, the Dahadinni River flows northeastward into the Mackenzie. Research efforts for the most part have been concentrated on the east side of the Mackenzie and therefore little terrain information is available for rivers on the west.

The Dahadinni drains a major area of the Mackenzie Mountains with the lower part in Area IV. It meanders strongly, forming a floodplain with low terraces up to about a half mile wide, enclosed by scarps up to 300 feet high consisting for the most part of till over shale and some sandstone, or near its mouth, alluvial sand and gravel. The floodplain deposits and associated terraces consist of sand and gravel with some overlying silt.

Approaches to pipeline crossings of the Dahadinni are potentially hazardous. The till in this area is relatively stone free with a high percentage of silt and clay that may contain ground ice. Better drained sites, near scarp edges, are more likely to be ice-free but are subject to failure due to rotational shears, mudflows, gullyng, undercutting, and erosion, the latter caused by meandering of the river. Sand and gravel present in the floodplain and associated terraces are ice free although the fine-grained colluvium that overlies the terraces may contain ground ice.

7.4.3.6 Johnson River

South of the Dahadinni, the next river of any consequence is the Johnson which originates in the piedmont area of the Mackenzie Mountains with only its lower portion present in Area IV. The Johnson River meanders strongly, forming a floodplain about 1/4 mile wide enclosed

by scarps up to about 300 feet high. The scarps, as they consist of relatively stone-free, silty, clayey till overlying poorly resistant shale and sandstone, are subject to failure. The till contains ground ice below bogland and poorly drained areas. An exception is near the mouth of the river where the scarps consist of sand and gravel of alluvial terraces that have formed along the Mackenzie. The floodplain and low associated terraces consist of sand and gravel and are commonly overlain by fine-textured colluvium, possibly containing ground ice, eroded from the scarps above.

The problems in laying a pipe across the Johnson are similar to those of the Dahadinni, although the Johnson has a lower volume and rate of flow and in general should be more easily crossed.

7.4.3.7 Wrigley River

The Wrigley is a strongly meandering river, flowing north along a valley west of the Camsell Range and then east across the broad valley of the Mackenzie. It dissects glacial deposits forming a floodplain and low associated terraces up to a mile wide. On the south side of the river, scarps, some over 200 feet high, expose thick till sections that are relatively stone-free, very silty and clayey and contain ice. Retrogressive thaw-flow slides are common, initiated by meander undercutting (Fig. 29). On the north side of the river, the scarps are slightly lower and more stable, composed for the most part of ice-free gravel and sand of glacial and post-glacial fluvial origin. An exception occurs toward the west where the river cuts through till overlying poorly resistant shale and sandstone.

The floodplain and associated terraces consist of gravel and sand with overlying colluvium. Ground observations indicate that these deposits are ice-free.

Pipeline construction difficulties may be encountered in the higher scarps, especially on the south side. Removal of organic matter can cause retrogressive thaw-flow slides, rotational shears, mudflows and gullyng. A warm line would melt ice, causing additional problems. An approach with ice-free conditions disturbing the organic cover as little as possible is recommended.

A line could be buried beneath the riverbed without much difficulty. The greatest hazard would be undercutting and erosion by lateral migration.

7.4.3.8 Root River

The Root River drains a large area of the Mackenzie Mountains. It enters Area IV from the west, flows south and then east into the

Mackenzie just above Camsell Bend. It is a braided river with a large seasonal variation of volume and rate of flow. It cuts through till, lacustrine silt and clay, and alluvial terraces and fans, forming a floodplain and associated alluvial terraces up to 2 miles wide. The lower part, the only practical place for a pipeline crossing, cuts through fine-grained lacustrine silt and clay with occasional coarser fluvial sediments. The lacustrine sediments generally have thick overlying bog deposits that are undergoing active thermokarst subsidence indicating widespread permafrost and ground ice. Removal of the organic cover during pipeline construction will cause the same types of problems with respect to effects on terrain and potential damage to the pipeline as those described for similar situations at other river crossings. It is recommended that the approaches to the river be in well-drained terrain with a minimum of ground ice, and that the organic cover be disturbed as little as possible.

The floodplain and associated terrace deposits consist of unfrozen silt, sand and gravel, causing little trouble in pipeline burial. The river itself is the problem. Burial will be difficult because of erratic shifting of channels, unpredictable aggradation and degradation, and bank erosion caused by spring flooding and break-up. Suitable foundation material can be located for a suspended line in the post-glacial coarse sediments.

7.4.4 Pipeline Construction Problems

Part of Area IV contains terrain conditions which will cause major construction problems. These include: 1) thick organic matter consisting of unfrozen fenland and frozen bogland, 2) active thermokarst subsidence, 3) fine-grained ice-rich lacustrine sediments, 4) fine-textured till that may contain a high percentage of ground ice (Figs. 30, 31, 32) and, 5) many river crossings with hazardous approaches.

There are three possible routings: west of the Mackenzie River, between the Mackenzie River and Franklin Mountains, and east of the Franklin Mountains.

The best routing based on terrain considerations is east of the Franklin Mountains. Continuing the routing from Area III, enter Area IV in the south-central part and head roughly north. The routing here is divided in order to avoid a depression of poorly drained, fine-grained sediments with a thick organic cover in which thermokarst subsidence is active. On the east side of the depression, the line would run through a fairly well drained till plain with only minimum variation in local relief and regional slope that should be easily managed. A few abandoned meltwater channels will have to be crossed but these are minor and should offer little difficulty. On the west side of the depression, the terrain is not as desirable but is still adequate. The topography and lithology are more varied with the presence of thin (mostly < 4 feet thick) lacustrine silt and sand overlying till, coarse glacial and post-glacial fluvial sediments, and till.

Northward from the Willowlake River to River Between Two Mountains, terrain conditions are adequate although here fairly well-drained till, with morphology consisting of drumlinoid ridges and flutings to relatively flat plains, and coarse glaciofluvial sediments including eskers and kames are present. However, there are areas to avoid that consist of thick organic terrain and lacustrine silt and clay. Continuing east of the Franklins, up the valley of the River Between Two Mountains, fairly well drained till, some associated with southeast-trending drumlinoid ridges and flutings, thin till over bedrock, and colluvium are encountered. Gentle slopes and occasional abandoned meltwater channels will have to be crossed but they should not cause major difficulties. At the west end of Fish Lake, the routing trends north-eastward through till with little surface morphology except for a few crevasse fillings and flutings. There is bogland in this area, so that details of the specific route will have to be chosen carefully. Next, the route shifts to the northwest, running parallel to a major fluting field that continues to about Blackwater Lake. It should be possible to locate lines in relatively ice-free, well-drained parts of these flutings. On the south side of Blackwater Lake, the corridor shifts to the north and then along the east side of the lake. The terrain and lithologic types are variable in this area and consist mostly of hummocky, fluted and drumlinized till, and glacial and post-glacial fluvial gravel and sand. Thick organic matter is present in a few areas but can be avoided. The Blackwater River will have to be crossed, but should not cause major difficulties because the river meanders only slightly with its floodplain and channel material being mostly sand (Fig. 33). North of the river, a till plain and south-west-trending flutings will be encountered but they should not be major obstacles.

A second routing is between the Mackenzie River and Franklin Mountains. This routing has been favoured by industry and is followed by the highway, but it does have certain disadvantages that the routing east of the Franklins does not have. The routing is the same for both from the boundary of Area III and Area IV to just north of Willowlake River. From here northward, conditions change. North to about the River Between Two Mountains on the west side of the Franklins, drumlins, striking northwestward and composed of till, cover most of the proposed routing. The crests of the drumlins are well drained and are probably permafrost-free whereas, in depressions where drainage is poor, permafrost and subsequently ground ice may be present. Construction problems in the better drained areas will be relatively minor with one major exception. Huge boulders, commonly several feet across, are found on the crests of the drumlins. Removal of these boulders may be difficult.

For most of the routing north of the River Between Two Mountains the terrain is underlain by lacustrine silt and clay with a high percentage of ground ice, and widespread occurrences of organic matter, mostly bogland. These conditions, of course, offer major problems and unfortunately are multiplied by numerous rivers that have to be crossed if this routing is followed. There are, however, abandoned meltwater

channels, some of which form discontinuous terraces along the Mackenzie, that may be utilized during construction. Although ice-rich silt may overlies portions of these channels, chances are fairly good that relatively ice-free, coarser materials will be encountered.

A third possible routing lies west of the Mackenzie River and east of the Mackenzie Mountains. The terrain consists mostly of ice-rich lacustrine silt and clay and till, some forming well-drained, ice-free drumlins and hummocks. Although the presence of till improves the terrain conditions on this side of the river compared to the other side, disadvantages are that braided rivers would have to be crossed as well as the Mackenzie unless, of course, the routing was placed west of the Mackenzie at Camsell Bend in Area III. However, there would be added terrain problems, as explained above, that would have to be overcome in the Camsell Bend area.

7.4.5 Views and Comments

Area IV has three possible pipeline corridors, each one with certain advantages and disadvantages with respect to terrain consideration. However, the routing east of the Franklin Mountains offers the fewest terrain problems although logistical and economical problems arise due to the distance from the Mackenzie River and Highway, the chief transportation routes of the area, and the potential for environmental damage on the long access route. Moreover, if a pipeline were routed east of the Franklin Mountains in this area, it logistically should continue northward east of the mountains across the Bear River and would not return to the Mackenzie River until it reached Fort Good Hope.

The big advantage of the routing east of the Mackenzie and west of the Franklins is the proximity to the river and highway. Construction costs will certainly be lower and access roads will be at a minimum. As stated above, the terrain for the most part is poor, consisting of ice-rich lacustrine silt and clay and bogland.

The third alternative is probably not as desirable as the other two. The big disadvantages lie in the necessity of crossing the Mackenzie and its braided tributaries. Deposit types vary between ice-rich silt and clay and well-drained, ice-free till. The presence of till does not outweigh the disadvantages of the river crossings and ice-rich sediments.

No matter what routing is chosen, it will be possible to select the preliminary routing from surficial geological maps. Then it will be necessary to obtain specific information on the texture and lithology of deposits, distribution of permafrost and ground ice, surface drainage and character of organic terrain for the best exact routing.

8. NEEDS FOR FURTHER STUDY

As discussed under the heading "Current State of Knowledge", there are more data to assimilate and analyses to be done from the field work carried out during the past two years. However, adequate information was available to construct surficial geology and geomorphology maps, to discuss the terrain and propose, in a general way, the best pipeline routing. More field work under the present terms of reference is not going to greatly alter the discussion presented.

Future terrain investigations should concentrate, in more detail, on a more specific routing. This would include such investigations as: exact distribution of permafrost and ground ice; rates and other characteristics of surface runoff; performance of materials from the engineering standpoint; detailed description, thickness and distribution of surficial deposits and bedrock; location of aggregate; and engineering characteristics, distribution, and moisture content of organic terrain. In addition, more information is needed on characteristics of rivers, streams, and creeks, the thermal properties of materials in permafrost areas, effects of fire- and man-induced thermal disturbance in permafrost materials, and geomorphic process studies, particularly characteristics and mode of origin of failure types.

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Figure 4. Section consisting of two Laurentide Tills separated by grey stratified drift. Located southwestern part Ft. Simpson map-area (95H). (61°06'N. Lat.; 121°19'W. Long.).



Figure 5. Trench Lake located in a north-south valley of the Mackenzie Mountains (Root River, 95K) that served as a meltwater channel during deglaciation.



Figure 6. Over two hundred feet of lacustrine sand deposited as a result of damming during deglaciation of the eastern flanks of the Mackenzie Mountains (61°42'N. Lat.; 123°58'W. Long.).



Figure 7. Up to about ten feet of till overlying shale near Willow Lake River in Bulmer Lake map-area (95I). Note the irregular hummocky surface of the till. (62°38'N. Lat.; 120°25'W. Long.).

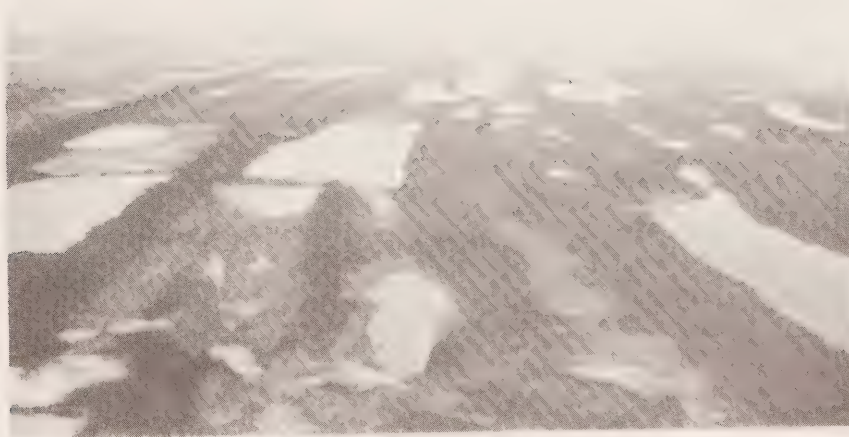


Figure 8. Typical flutings consisting of till found throughout area of investigation. Note the high stands of conifers on the better drained ridges. Airview near Great Bear Lake.



Figure 9. Typical stony till found through much of the mountainous area in the western part of the area of investigation. (Camsell Bend map-area, 95J).



Figure 10. Raised peat plateau (bogland) bordered by fenland found in various locations throughout the plains of the area investigated (Sibbeston Lake map-area, 95G).



Figure 11. Peat palsas (bogland) about 12 feet high bordered by Fenland. (Camsell Bend map-area, 95J).



Figure 12. Confluence of the Liard and Mackenzie Rivers near Ft. Simpson. Bluffs of lacustrine sediments overlying till can be seen in the background. (Ft. Simpson map-area, 95H).



Figure 13. North slope of the Martin Hills blanketed by till. The Camsell Range of the Franklin Mountains can be seen in the background. View toward the northwest (Sibbeston Lake map-area, 95G).



Figure 14. A part of the Camsell Range of the Franklin Mountains, bordered by plains and the Ram River to the east. Note the glacial scouring on the summit area. (Camsell Bend map-area, 95J).



Figure 16. Retrogressive thaw flow slide located in ice-rich fine-grained sediments on the Johnson River.



Figure 17. Close-up of an actively thawing face about 20 feet high of a retrogressive thaw flow slide. Note the steepness of the face and the reticulated network of ground ice (coated with wet silt). This slide is in lacustrine clayey silt located in a valley of the Mackenzie Mountains in the Root River map-area (95K).



Figure 18. Close-up of a silt coated ice wedge in another part of the face of the retrogressive thaw flow slide seen in Figure 17.

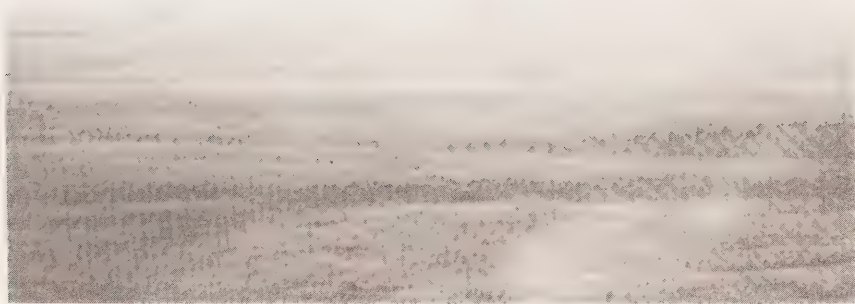


Figure 19. Typical piedmont of the Mackenzie Mountains on the west side of the Mackenzie River in the Root River map-area (95K). The terrain is dissected with thin till overlying shale.



Figure 21. Active-layer detachment slide in till, following a forest fire, near the Wrigley River in the southwest part of the Wrigley map-area (950).



Figure 22. Close-up of active-layer detachment slide seen in Figure 21.



Figure 23. Ice-rich gravels exposed by recent river erosion. These are common at higher elevations in glacial and post-glacial fluvial sediments in valleys of the Mackenzie Mountains in the Dahadinni and Root Rivers map-areas (95N, 95K).



Figure 24. Over 80 feet of till exposed along the Wrigley River in the southwest part of the Wrigley map-area (950). The till contains less than 5% pebble sized material or larger with roughly equal amounts of sand, silt and clay. (63°17'N. Lat.; 123°40'W. Long.).



Figure 25. Peat polygons exposed near the east flank of the Franklin Mountains in the Wrigley map-area (950). The vegetation is dominantly lichens and Ericaceous shrubs.



Figure 26. Close-up of an area of peat polygons near the east flank of the Franklin Mountains in the Wrigley map-area. Lichens and Ericaceous shrubs comprise most of the vegetation.



Figure 27. Ice-rich till exposed in an erosional gully at a drilling site where the organic mat was removed. The layered appearance of the till is due to ice layers about 1/4" to 1/2" thick (Wrigley map-area, 950, 63°14'N. Lat.; 123°55'W. Long.).



Figure 28. Cloudy ice, probably in a reticulated network, is exposed with lacustrine clayey silt. This is typical for fine grained sediments in Area IV. The outside diameter of the core barrel is 2".



Figure 29. A retrogressive thaw flow slide in relatively stone-free till. The ice content is low resulting in viscous material deposited at the base. The original face was exposed by river undercutting. (Wrigley map-area, 950, 63°14'N. Lat.; 123°55'W. Long.).



Figure 30. Gullying and collapse in ice-rich till at a drilling site as a result of hydraulic erosion and thermokarst subsidence after the organic mat had been removed (Wrigley map-area, 950, 65°14'N. Lat.; 123°55'W. Long.).



Figure 31. Saturated active-layer in till damaged by tracked vehicles with the formation of a river along a seismic line, southwest of Norman Wells, west of the Mackenzie River.



Figure 32. Close-up of river formed along a seismic line as seen in Figure 30. The river formed by erosion, following damage of the saturated active layer by tracked vehicles. The banks are in the order of 12 feet high.



Figure 33. View of the Blackwater River in the north-central part of the Wrigley map-area (950). River bars and banks consist mainly of sand.

10. APPENDIX A - FIELD DATA

10.1 EXPLANATION OF SYMBOLS AND TERMS

MAP SYMBOLS

- C. Data from reports prepared by Ripley, Klohn and Leonoff Alberta Limited, Consulting Engineers for the following clients: Job number FD1005-1008, Canadian Bechtel Limited, December 1969; Job number CA1032, Mackenzie Valley Pipe Line Research Limited, August 1970.
- P. Data from a report prepared by Pemcan Services for Alberta Gas Trunk Line, February 1972.
- G. Selected data from a report prepared by Gretchen V. Minning on Drilling in Surficial Deposits near Fort Simpson, Northwest Territories, and through personal communication.
- T. Selected data from reports prepared by C. Tarnocai of the Canadian Soil Survey, Canada Department of Agriculture. These data were collected while working with the author in the field during the summer of 1972.
- S. Summary of surficial deposits as reported in shot holes along seismic lines by the following companies: Chevron Standard Limited; Imperial Oil Limited; Amoco Canada Petroleum Company Limited; Shell Canada Limited; Northern Oil Explorers Limited; Aquitaine Company of Canada Limited; Pan Canadian Petroleum Limited, Mobil Oil Canada Limited; Sigma Explorations Limited.
- R. Selected data collected in field work by N.W. Rutter, G.V. Minning, and J.A. Netterville, 1971; N.W. Rutter, A.N. Boydell, G.V. Minning, and J.L. Domansky, 1972.
- D. Selected data from a report (project 85033) by F.E. Kimball, Project Manager N.W.T. Roads, Western Region, Department of Public Works, Canada.

PERMAFROST DESCRIPTION

The permafrost description used in this report follows the National Research Council of Canada publication, Guide to a Field Description of Permafrost. For a more extensive description of these terms, the reader is referred to Pihlainen and Johnston, 1963.

- N. group symbol indicating ice not visible.
 - Nf. poorly bonded or friable
 - Nbn. well bonded, no excess ice.
 - Nbe. well bonded, excess ice.

- V. group symbol indicating visible ice less than 1 inch thick.
 - Vx. individual ice crystals or inclusions.
 - Vc. ice coatings on particles.
 - Vr. random or irregularly oriented ice formations.
 - Vs. stratigied or distinctly oriented ice formations.
- ICE. group symbol indicating visible ice greater than 1 inch thick.
 - ICE + soil type. ice with soil inclusions.
 - ICE. ice without soil inclusions.

CLASSIFICATION BY PARTICLE SIZE

All analyses are based on the M.I.T. Grain Size Scale which is as follows:

- Boulders - greater than 200 mm
- Cobbles - 75 mm to 200 mm
- Gravel - 2 mm to 75 mm
- Sand - .0625 mm to 2 mm
- Silt - .002 mm to .0625 mm
- Clay - less than .002 mm.

The data given in this report are collected from several sources, and subsequently analyses have been carried out in several different laboratories. Although the classification by particle size was constant, the constituents recorded for each sample were not. For example in till samples, the gravel content may or may not have been recorded. Furthermore, where a number of constituents are present in near trace content (approximately 1%) they are frequently deleted from listing, as a result the sum of the percentages of each of the constituents may not be 100%.

DEFINITIONS

Plastic Limit (Pw) - the water content, expressed as a percentage of the weight of oven-dried soil, at which the soil begins to break apart and crumble when rolled by hand into threads 1/8 inch in diameter.

Liquid Limit (Lw) - the water content expressed as a percentage of the weight of oven-dried soil, at which a trapezoidal groove of specified shape, cut in moist soil held in a cup, is closed after 25 taps on a hard rubber plate.

Natural Water Content (w) - the ratio of the weight of water to the weight of solids in a given mass of soil; expressed as a percentage of the weight of oven-dried soil.

Bulk Density or Unit Weight (d) - the ratio of dry or wet weight of a soil mass to its unit volume. (expressed as d=dry & wet lbs/cu.ft.).

10.2 AREA I

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-1 (25/11/69)	unfrozen, water content high throughout, w=282% @ 8', free water at surface unfrozen, w=21% @ 22'	0' -20' FEN 20' -25' TILL, silt predominant, trace of organics
C-2 (25/11/69)	frozen Nbn, w=19% @ 5', w=12% @ 9'	0' - 1' ORGANIC 1' -15' TILL, clay predominant
C-3 (25/11/69)	Nbn, w=13% @ 5', w=11% @ 10'	0' - 1' ORGANIC 1' -12' TILL, silt predominant (40%, sand 29%, clay 25%) Pw=17%, Lw=26% @ 8'
C-4 (25/11/69)	frozen unfrozen to 6', Nbn from 6', w=13% @ 9', w=12% @ 15.5'	0' - 4.5' BOG 4.5' -15' TILL, silt predominant (42%, gravel 4%, sand 29%, clay 25%), Pw=17%, Lw=28% @ 9'
C-5 (25/11/69)	frozen w=19% @ 6'	0' - 2' ORGANIC 2' -15' SAND, silty, trace of clay
C-6 (24/11/69)	frozen to 2' unfrozen to 10' with free water unfrozen to 15', frozen to 20', w=12% @ 17'	0' -10' FEN 10' -20' TILL
C-7 (24/11/69)	Vs and Vr, w=750% @ 7.5', w=228% @ 11', Nbn, w=25% @ 13.5', w=19% @ 17.5'	0' -11.5' BOG 11.5' -17' SILT, clay, trace of organics 17' -20' TILL
C-8 (24/11/69)	unfrozen unfrozen to 5', Nbn to 14.5', w=13% @ 12'	0' - 3' CLAY, soft, silty, highly organic 3' -14.5' SILT, soft to .5', sandy, clayey, trace of organics
C-9 (24/11/69)	frozen unfrozen unfrozen to 5' Nbn to 16' w=12% @ 5', w=10% @ 10'	0' - 2' ORGANIC 2' - 4' CLAY, black, organic 4' -16' SILT, soft to 5', sandy, traces of clay and organics

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-10 (9/11/70)	unfrozen to 2', Vx to 14' w=480% @ 3', w=583% @ 6', w=785% @ 11' Vx, w=38% throughout	0' -14' BOG, peat with wood fibres 14' -22' TILL, silt predominant (44%, sand 32%, clay 24%), d=60 & 85 lbs/cu.ft. @ 16' d=86 & 120 lbs/cu. ft. @ 21'
C-11 (9/11/70)	unfrozen to 2' Vx to 14' w=758% @ 3', w=676% @ 7', w=689% @ 11', Vx w=47% @ 16' w=41% @ 21'	0' -14' BOG, fibrous, brown peat 14' -22' SILT, clayey (30%), d=80 & 118 lbs/cu.ft. @ 16' d=83 & 120 lbs/cu.ft. @ 21'
C-12 (9/11/70)	unfrozen unfrozen, w=19% @ 3', w=17% @ 6', w=15% @ 10', w=14% @ 15'	0' - 2' SILT, soft, organic, sandy 2' -17' TILL (sand 33%, silt 39%, clay 28%) Pw=18%, Lw=30% @ 6' d=130 & 149 lbs/cu. ft. @ 10'
C-13 (8/11/70)	unfrozen unfrozen, w=18% @ 3', w=14% @ 9', w=13% @ 21'	0' - 2' ORGANIC, silty, below 1' 2' -22' TILL (sand 28%, silt 33%, clay 36%), 1' zone coarse gravel 18' to 19', d=124 & 139 lbs/cu.ft. @ 9', d=124 & 140 lbs/cu.ft. @ 21'
C-14 (8/11/70)	unfrozen, w=510% @ 3', w=542% @ 11' unfrozen, w=14% @ 16', w=10% @ 21'	0' -12' FEN, odorous, fibrous, brown, soft 12' -22' TILL (sand 37%, silt 38%, clay 27%) d=135 & 152 lbs/cu.ft. @ 16'
C-15 (8/11/70)	unfrozen to 2' Vx and Vr to 9.5', w=268% @ 3', w=355% @ 6' Vx, w=18% @ 11', w=16% @ 16' w=11% @ 21'	0' - 9.5' BOG, peat, fibrous, wood chips, very silty 6.5' to 7', d=15 & 65 lbs/cu.ft. @ 6' 9.5' -22' TILL (sand 39%, silt 34%, clay 24%), coarse gravel 17' to 19' d=107 & 126 lbs/cu. ft. @ 11', Pw=15%, Lw=24% @ 11'

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-16 (6/11/70)	unfrozen, saturated, 0' - 9' w=742% @ 3' unfrozen, w=17% @ 11', 9' -20' w=13% @ 15', w=11% @ 19',	FEN, fibrous, soft TILL (gravel 22%, sand 20%, silt 34%, clay 24%, gravel reduces to 4% after 15'), Pw=17%, Lw=23% @ 11' Pw=18%, Lw=29% @ 15'
C-17 (6/11/70)	unfrozen 0' - 2' unfrozen to 15', 2' -22' Vx to 20' Nbn to 22', w=9% @ 2', w=13% @ 11', w=8% @ 21'	ORGANIC, very silty, soft TILL (sand 39%, silt 28%, clay 30%), coarse gravel and cobbles 12' to 15'
C-18 (6/11/70)	unfrozen 0' - 1' unfrozen, w=18% @ 3' 1' - 4' unfrozen, w=16% @ 6', 4' -22' w=10% @ 11', w=13% @ 15', w=7% @ 21'	ORGANIC, fibrous SILT, soft, organic (3.8%), d=105 & 123 lbs/cu.ft. @ 3' TILL (gravel 5%, sand 40%, silt 30%, clay 25%), rust stains common, coarse gravel 12' to 14' Pw=17%, Lw=25% @ 11'
T-1 (5/8/72)	This location represents four probes in close proximity.	
hole 1	unfrozen 0' - 8' unfrozen 8' plus	FEN SAND
hole 2	unfrozen 0' - 7' unfrozen 7' - 9.4'	FEN SAND
hole 3	unfrozen to 1.8', 0' - 9.5' frozen to 9.5' frozen 9.5'-10.5'	BOG SAND
hole 4	unfrozen 0' - 2' 2' - 6'	BOG VARIABLE

MAP SYMBOL	SUMMARY OF DATA	
S-1	0' -40'	CLAY, except at the midpoint of the line where sand and gravel or gravel make up the top 15'
S-2	0' - 4' 4' -12' 12' -40'	ORGANIC, in the west only CLAY, extends right to the surface and contains a lot of sand in the east TILL, in the centre and west, high in sand and gravel content
S-3	0' -40'	TILL, very high sand and gravel content from the midpoint of the line to its eastern limit
S-4	0' -40'	TILL, infrequent thick organic cover in the northern half of the line
S-5	0' -40'	TILL, increasing content of sand and gravel northward
S-6	0' -15' 15' -40'	CLAY or SAND & GRAVEL, no pattern to the occurrence of either, cap may vary plus or minus 5' in thickness TILL, very clayey in the extreme south and very sandy in the extreme north
S-7	0' -40'	TILL, distinct clay zones near the top in the west, also frequently an organic veneer in the west
S-8	0' - 6' 6' -40'	ORGANIC, sometimes clay or gravel in the southeast end. Permafrost near the surface of the intersection of S-10 TILL, high in sand and gravel content
S-9	0' -40'	TILL, organic veneer common at both ends of the line, high in sand and gravel content. Permafrost near the surface in the extreme southeast end of the line
S-10	0' -40'	TILL, high in sand and gravel content except at the midpoint where clayeyness is predominant
S-11	0' -40'	TILL, gravelly, organic veneer
S-12	0' -40'	TILL, gravelly, organic veneer
S-13	0' -40'	TILL, very clayey, especially in the extreme north
S-14	0' -10' 10' -40'	CLAY, or clayey till commonly with an organic veneer TILL, high in sand and gravel

MAP SYMBOL		SUMMARY OF DATA
S-15	0' -40'	TILL, high in sand and gravel content, infrequent organic veneer in the west
S-16	0' - 5' 5' -40'	ORGANIC TILL, sandy
S-17	0' -40'	TILL, organic veneer in the east
S-18	0' -40'	TILL, organic veneer in the south
S-19	0' -10' 10' -40'	ORGANIC, thins to 1' at midpoint of line TILL, distinct (5') zones of gravel, sand or clay encountered
S-20	0' -10' 10' -40' 40' plus	ORGANIC TILL, variable thickness, sandy SANDSTONE
S-21	0' -40'	VARIABLE, complete or interbedded zones of sand, gravel, sand and gravel or clay. Sandstone and shale bedrock encountered in central part - outcrop only near the highway
S-22	0' -40'	TILL, commonly distinct zones of sand, gravel, or sand and gravel interbedded with till. Sandstone bedrock encountered as high as 15' below the surface in the southern half
S-23		
(southern half)	0' - 6' 6' -15' 15' -40'	ORGANIC CLAY, not always present SHALE, sometimes in outcrop
(northern half)	0' -10' 10' -40'	TILL, very gravelly SANDSTONE & LIMESTONE, sometimes in outcrop
S-24		
(southern half)	0' -40'	TILL, frequently with an organic veneer
(northern half)	0' -40'	VARIABLE, approximately 60% of the holes are in shale, sandstone or limestone, the remaining 40% are in till or gravel
S-25	0' -15' 15' -45'	SAND & GRAVEL, thickens to entire section, toward the Mackenzie River SANDSTONE & LIMESTONE
S-26	0' -15' 15' -40'	ORGANIC, frequently frozen TILL, clayey, bedrock encountered several times in the north at about the 30' level

MAP SYMBOL	SUMMARY OF DATA	
S-27	0' -40'	TILL, frequently gravelly where the line crosses streams flowing into the Mackenzie River
R-1	0' - 2' 2' plus	SAND & SILT TILL
R-2	0' - 1.5' 1.5' plus	SILT & SAND TILL
R-3	0' - 1.5' 1.5' plus	TILL, bouldery SILT
R-4	0' - 0.7' 0.7' plus	SILT TILL, bouldery
R-5	0' - 1' 1' plus	SILT TILL
R-6	0' - 2' 2' plus	SILT TILL (sand 32.4%, silt 30.8%, clay 36.8%)
R-7		TILL, sandy, 20% inclusions
R-8	probing showed 1' to permafrost	
R-9	0' - 1' 1' plus	TILL LIMESTONE
R-10		SILT, lacustrine overlying till
R-11	0' - 4' 4' - 9' 9' plus	SILT, lacustrine TILL LIMESTONE
R-12	0' - 1' 1' - 5'	SILT TILL
R-13		SILT, lacustrine, overlying shale and limestone
R-14	0' - 2' 2' -12' 12' plus	SILT GRAVEL SHALE & LIMESTONE
R-15	0' - 4' 4' plus	TILL, very silty GRAVEL
R-16	0' -12' 12' plus	TILL SHALE & LIMESTONE
R-17		SHALE & LIMESTONE

MAP SYMBOL		SUMMARY OF DATA
R-18	0' -50'	TILL, lower unit (sand 37.2%, silt 29.0%, clay 33.8%), upper unit (sand 36.2%, silt 29.0%, clay 34.8%)
R-19	0' - 1.5' 1.5' - 2.0' 2' -12' 12' -42'	SILT, contains CaCO ₃ SAND TILL, reworked, contains bands of black shale TILL
R-20	0' -40' 40' -60' 60' -65'	TILL, slump in centre 10' (sand 34.2%, silt 28.0%, clay 37.8%) SAND & GRAVEL, interbedded BOULDERS, and coarse gravel
R-21	0' - 3' 3' - 4' 4' -14'	TILL, weathered and silty (sand 49.2%, silt 24.6%, clay 26.2%) GRAVEL & SAND, interbedded, contains grey shale chips SHALE, weathered, grey
R-22		TILL, sandy (sand 45.2%, silt 22.6%, clay 32.2%)
R-23		SAND, very fine, silty and clayey, inclusions of pebbles and cobbles all over till
R-24	0' - 1.5' 1.5' plus	SAND TILL (sand 32.2%, silt 29.6%, clay 38.2%)
R-25	0' - 3' 3' - 5' 5' -17' 17' -25'	SILT, laminated with lenses of organic matter GRAVEL TILL (sand 36.6%, silt 28.4%, clay 35.0%) SLUMP
R-26	0' - 0.5' 0.5' plus	SILT TILL, (sand 28.2%, silt 24.0%, clay 47.8%)
R-27	0' -30'	TILL (sand 32.2%, silt 26.0%, clay 41.8%)
R-28		TILL (sand 35.2%, silt 31.0%, clay 33.8%)
R-29	0' - 0.5' 0.5' -4.5'	SILT GRAVEL, poorly sorted
R-30	0' - 1.5' 1.5' plus	SILT TILL
R-31	0' - 1' 1' plus	SILT TILL

MAP SYMBOL		SUMMARY OF DATA
R-32	0' - 1' 1' - 2'	SILT CLAY
R-33	0' - 1' 1' plus	SILT TILL
R-34	0' - 1' 1' plus	CLAY, silty TILL
R-35	0' - 1.5' 1.5' plus	CLAY, silty TILL
R-36	0' - 1' 1' -50'	SILT, sandy TILL, low in clay context, slumped
R-37	0' - 2' 2' plus	SILT & SAND TILL
R-38	0' - 1' 1' plus	SILT & SAND TILL
R-39	0' -10' 10' plus	GRAVEL TILL
R-40	0' - 2.5' 2.5' plus	SILT, gritty, lacustrine TILL
R-41	0' - 0.67' 0.67' plus	SILT, colluviated TILL
R-42	0' - 1' 1' plus	SILT, colluviated TILL
R-43	0' - 1.5' 1' plus	SILT TILL
R-44	0' - 3' 3' plus	SILT, fine sand SAND, coarse
R-45	0' - 1' 1' plus	SILT TILL
R-46	0' - 1' 1' plus	SILT TILL
R-47	0' - 4' 4' plus	SILT TILL
R-48	0' - 0.5' 0.5' plus	SILT TILL

MAP SYMBOL		SUMMARY OF DATA
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R-49	0' - 30' 30' plus	GRAVEL & SAND TILL
R-50	0' - 2' 2' plus	ORGANIC TILL
R-51	0' - 2.5' 2.5' plus	SILT TILL
R-52	0' - 1' 1' plus	SILT TILL
R-53	0' - 2' 2' plus	ORGANIC SILT
R-54	0' - 0.5' 0.5' plus	SILT TILL

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
R-55 (5/8/72)	very wet, unfrozen to 2.5', Vx to 6.5', unfrozen to 9.33' unfrozen	0' - 9.33' BOG, sphagnum, consolidation increases downward 9.33 plus TILL, silty, sandy, gritty
R-56 (5/8/72)	unfrozen to 2.5', Vx and Vr increasing downward to 25% by volume Vx and Vr and ice up to 2 inches thick	0' - 9.5' BOG, sphagnum 9.5'-11.5' TILL, sandy, silty, gritty
R-57 (6/8/72)	unfrozen and very moist to 0.67', Nbe grading to Vr near the base, (15% ice at base) Vr (20% ice by volume) Vr (15% ice by volume)	0' - 9.5' BOG, sphagnum, becoming silty at base 9.5'-12' SILT, organic with wood fibres 12' plus TILL
R-58 (7/8/72)	unfrozen to 0.5', Nbe grading to Vs, downward unfrozen	0' - 10.5' BOG, sphagnum, twigs, leaves and fibres throughout 10.5'-12.5' SILT, clayey
R-59 (7/8/72)	unfrozen to 1', Nbe grading to Vr downward unfrozen high water content	0' - 10.5' BOG, sphagnum, frequently with twigs and leaves 10.5' plus SILT, badly disturbed

MAP SYMBOL		SUMMARY OF DATA
R-60		TILL, sandy, stony, highly calcareous
R-61	0' - 60'	SAND & GRAVEL
	60' - 70'	TILL, calcareous, stony
	70' - 74'	SAND, coarse
	74' - 89'	GRAVEL medium to fine
	89' - 110'	GRAVEL & SAND, cemented
R-62	0' - 20'	TILL, stony, highly calcareous
R-63	0' - 4'	SILT, lacustrine
	4' - 44'	SAND, medium
R-64	0' - 45'	GRAVEL, medium sized at top grading to coarse
	45' plus	TILL
R-65	0' - 30'	GRAVEL & SAND
R-66	0' - 30'	GRAVEL & SAND
R-67	0' - 20'	TILL
R-68	0' - 4'	SILT, floodplain
	4' - 5'	SAND, medium to coarse
	5' - 15'	GRAVEL & SAND
R-69	permafrost probe on palsa - on hummock, 20" to frost and next to hummock 28" to permafrost. A 1' veneer of organics is everywhere present.	
R-70	permafrost probe - 22" to frost	
R-71	permafrost probe on palsa - on hummock 19" to frost and next to hummock 16" to frost.	
R-72	permafrost probe on palsa - on hummock 18" to frost and next to hummock 13" to frost.	
R-73	permafrost probe on palsa - on hummock 19" to frost and next to hummock 13" to frost	
R-74	permafrost probe - in fen area 6' penetration and no permafrost Beside this swampy area on palsa, on a hummock 17" to frost and next to hummock 13" to frost.	
R-75	0' - 2'	ORGANIC, probe made here showed 6' to permafrost
	2' plus	TILL
	beside this swampy area, on hummock 27" to frost and next to hummock 18" to frost.	

MAP SYMBOL

SUMMARY OF DATA

R-76	0' - 2' 2' plus	ORGANIC, probe made here found no permafrost TILL
R-77	0' -25'	SAND, coarse & GRAVEL, fine; glaciofluvial (gravel 26.9%, sand 71.4%, silt and clay 1.2%)
R-78		ESKER, variable width - 100' average width, 45' high, mixed sand and gravel (gravel 32.6%, sand 56.1%, silt and clay 9.6%)
R-79		TILL (sand 36.4%, silt 28.4%, clay 35.2%)
R-80		TILL, (sand 32.4%, silt 23.4%, clay 44.2%)
R-81		SAND & GRAVEL, glaciofluvial ridge, 130' high and 125' wide (gravel 28.1%, sand 57.1%, silt and clay 14.8%)
R-82	0' - 1.5' 1.5' plus	SAND, very fine TILL, clayey (clay 38.2%, silt 29.6%, sand 32.2%)
R-83		TILL, (sand 22.4%, silt 34.6%, clay 43.0%)
R-84		GRAVEL, lacustrine, beach, (gravel 89.9%, sand 8.6%, silt and clay 1.2%)
R-85	0' -10' 10' -40'	GRAVEL, sandy TILL, (sand 22.8%, silt 30.4%, clay 46.8%)

10.3 AREA II

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-1 (23/11/69)	frozen 0' - 2' unfrozen 2' - 9', frozen 9' - 16', w=34% @ 4', w=18% @ 6', w=10% @ 15'	0' -16' SILT, sandy, organic, trace of clay
C-2 (22/11/69)	frozen frozen, w=12% @ 4' frozen, w=12% @ 8' w=11% @ 15'	0' - 0.7' ORGANIC 0.7'- 5' SAND, silty and clayey 5' -16' TILL
C-3 (22/11/69)	frozen to 2' unfrozen to 5.5' with free water unfrozen to 12', Nbn to 15', Nbe to 20', w=28% @ 11', w=30% @ 18'	0' - 5.5' FEN 5.5'-20' SILT (60%) & CLAY (40%) organic P Pw=22%, Lw=37% @ 11'
C-4 (22/11/69)	Nbn, w=11% @ 7'	0' - 4.5' GRAVEL 4.5'-15' SAND, fine, trace of silt and organics
C-5 (5/11/70)	unfrozen to 2', Nbn to 5.5', w=273% @ 2', w=29% @ 5' Nbn Nbn, w=22% @ 11', w=23% @ 15', w=24% @ 21'	0' - 5.5' BOG, root fibres 5.5'- 7' SILT, clayey 7' -22' SAND, very fine, silty (13%), d=74 & 90 lbs/cu.ft. @ 11'
C-6 (5/11/70)	unfrozen unfrozen, w=22% @ 3', w=25% @ 11' unfrozen, w=18% @ 16'	0' - 2' ORGANIC 2' -11.5' SAND & SILT (42% each, clay 16%), trace of organics 11.5'-22' SAND, very fine, loose (silt 33%)
C-7 (6/11/70)	unfrozen to 2' Vx to 3.75', w=148.7% @ 3' Vx, w=46% @ 5', w=35% @ 10', w=127.1% @ 15', w=42% @ 20', ice content 50% to 60% by volume 15' to 22'	0' - 3.75' ORGANIC, root fibres, trace of sand and silt 3.75'-22' CLAY, very silty, d=74 & 107 lbs/cu.ft. @ 5', d=93 & 127 lbs/cu.ft. @ 10', d=35 & 80 lbs/cu.ft. @ 15'

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-8 (5/11/70)	unfrozen unfrozen w=9% @ 3', w=3% @ 5', w=6% @ 21'	0' - 2' ORGANIC, sandy, rootlets 2' -22' SAND, very fine, trace of organics and trace of silt (3%)
C-9 (5/11/70)	unfrozen to 2', Vx to 6.5', w=586% @ 4', w=28% @ 6' Nbn Vx, w=35% @ 11' unfrozen, saturated, w=26% @ 16' w=22% @ 21'	0' - 6.5' BOG, silty, d=8 & 58 lbs/cu.ft. @ 4' 6.5'- 9.5' SAND, fine to medium, trace of silt and organics 9.5'-14.5' SILT, sandy (11%) 14.5'-22' SAND, fine, trace of silt and organics
C-10 (5/11/70)	unfrozen, w=65% @ 3', w=112.9% @ 6' unfrozen, w=49% @ 11', w=16% @ 15', w=26% @ 20'	0' -10' FEN, fibrous, laminated with layers of silty sand 10' -22' SAND, very fine, organic (5%) trace of silt (10%), loose

MAP SYMBOL

SUMMARY OF DATA

G-1	Moving west from centre line at mile 264.1
0' -15'	SAND, may be as high as 30' near the highway and grading as low as 5' at the west end of the line.
15' -45'	CLAY or CLAYEY TILL, varies in thickness from 5' in the extreme west to 50' under and immediately west of centre line.
45' plus	SHALE & LIMESTONE, dips gently to the east encountered at 30' under centre line, 25' in the extreme west and 50' in a hole about midpoint between.
	Moving east from centre line at mile 264.1
0' -20'	SAND & GRAVEL, thickens eastward to 30', also in the east permafrost (20' thick) was encountered in holes with a 5' sphagnum cap and thin interbeds of clay in the sand and gravel.

MAP SYMBOL

SUMMARY OF DATA

20' -50'
50' plus
TILL, silty and clayey, sometimes with distinct gravel interbeds.
GRAVEL, shale and limestone bedrock were encountered in two holes near the east end at about 60'.

G-2

Moving north from centre line at mile 229.9

0' -10'
10' -17'
17' -50'
50' plus
BOG, sphagnum, frequently frozen throughout and into the silt below.
SILT, frequently clayey and frozen.
TILL, silty and clayey, ranges from 10' thick in extreme north to 105' slightly south of the midpoint.
SHALE, encountered at 30' in the north and just north of the centre line.

Moving south from centre line at mile 229.9

0' -10'
10' -40'
40' plus
SILT, or silty till, sometimes with up to 5' of organic cover. Thick zones of frost encountered but no permafrost.
TILL, silty and clayey, thins just north of midpoint where limestone and shale are encountered at between 15' and 20'. Becomes slightly thicker in the extreme south. Frequently interbedded gravel.
LIMESTONE & SHALE

MAP SYMBOL
(date drilled)

FROST AND
MOISTURE DATA

LITHOLOGY AND
ENGINEERING DATA

T-1 (8/6/72)

This location represents two probes in close proximity.

hole 1

0' - 0.1' SILT
0.1'- 1.8' CLAY

hole 2

unfrozen to 0.8',
Vx and Vr to 7.5',
unfrozen to 2.7'
unfrozen

0' - 2.7' ORGANIC, sphagnum
2.7'- 3.3' CLAY

T-2 (9/6/72)

unfrozen to 1',
Vx, Vr and ice to 12'
(ice content up to
90% by volume at 10.5')
Nbn to 17.5',
unfrozen to 17.8'

0' -12' BOG, peat plateau
12' -17.8' CLAY, laminae of peat

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
T-3	unfrozen unfrozen	0' - 0.7' SILT 0.7'- 2.3' CLAY
T-4 (13/6/72)	This location represents three probes in close proximity.	
hole 1	unfrozen to 1.5' Vx and Vr to 11' Vx, Vr and ice up to 4 inches thick and comprising 60% of the section at the base	0' -11' BOG, peat plateau 11' -17.5' TILL
hole 2	unfrozen to 0.7' Vx and Vr to 10.8' unfrozen	0' -10.8' BOG, palsa (developed in collapse scar) 10.8'-11.3' TILL
hole 3	unfrozen, free water, traces of seasonal frost unfrozen	0' - 8.8' FEN, collapse scar 8.8' plus TILL
T-5 (20/6/72)	unfrozen to 1.3' Nbe and Vr to 8.7' Vr and ice up to 1.5" thick	0' - 8.7' BOG, palsa 8.7' plus TILL
T-6 (16/6/72)	This location represents two probes in close proximity.	
hole 1	unfrozen	0' - 5.5' ORGANIC, peat plateau
hole 2	unfrozen unfrozen	0' -10' FEN 10' -13' TILL
T-7 (15/6/72)	This location represents two probes in close proximity.	
hole 1	unfrozen except for seasonal frost between 0.7' and 1.7', saturated unfrozen	0' -13.8' FEN 13.8'-15.8' TILL
hole 2	unfrozen to 0.7' Vr and ice up to 2 inches thick Vr and ice up to 1.5 inches thick	0' -19' BOG, wooded palsa 19' -21' TILL

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
T-8 (14/6/72)	This location represents two probes in close proximity.	
hole 1	unfrozen to 1' Vx and Vr to 21' frozen, high ice content, banded, milky ice	0' -21' BOG, wooded palsa 21' -22.3' TILL, silty and clayey
hole 2	unfrozen	0' -16.4' FEN, ash layer 1" thick at 2.33'
T-9 (21/6/72)	unfrozen to 1' Vx and Vr to 6.5' Vs	0' - 6.5' BOG, young palsa developed in collapse scar 6.5'- 7.6' TILL, gravelly
T-10 (26/6/72)		0' - 1.5' ORGANIC 1.5'- 2.7' SAND, lacustrine
MAP SYMBOL	SUMMARY OF DATA	
S-1	0' -45'	TILL, interbedded clays encountered in top 20' of section near the intersection of S-4. Permafrost defined in these clays
S-2	0' -45'	TILL, clay overlying sandstone in the centre of the line
S-3 (south of S-1)	0' -20' 20' -40'	SAND or GRAVEL TILL
(north of S-1)	0' -20' 20' -40'	TILL, clayey SANDSTONE
S-4	0' -45'	TILL, sandstone bedrock encountered only in the centre of the line
S-5	0' -45'	TILL, sandy and gravelly, sandstone and shale bedrock encountered only in the centre of the line.
R-1	0' - 4.5'	SAND, well sorted, very fine to fine
R-2	0' - 1.5' 1.5' plus	ORGANIC CLAY, frozen, Vx and Vr
R-3	0' - 2' 2' plus	SILT & GRAVEL CLAY & SILT

MAP SYMBOL	SUMMARY OF DATA	
R-4	0' - 8' 8' - 9.5' 9.5' plus	SILT SAND, gravelly TILL, veneer only over bedrock
R -5	0' - 2' 2' -37'	ORGANIC GRAVEL, sandy, numerous boulder inclusions
R-6	0' -17' 17' plus	GRAVEL LIMESTONE
R-7	0' -17' 17' plus	GRAVEL, well sorted, beach type LIMESTONE
R-8		BOG, sphagnum, frozen at 0.5'
R-9	0' -10' 10' -40'	GRAVEL, sandy TILL (sand 22.8%, silt 30.4%, clay 46.8%)
R-10		BOG, frozen at 0.8'
R-11	0' -20'	SILT
R-12	0' -20'	GRAVEL
R-13	0' -10' 10' plus	GRAVEL TILL, over bedrock
R-14	0' -10' 10' plus	GRAVEL LIMESTONE
R-15	0' -10' 10' plus	GRAVEL LIMESTONE
R-16	0' - 2' 2' plus	SILT TILL
R-17	0' - 2.5' 2.5' plus	SILT TILL, gravelly
R-18	0' -10' 10' plus	TILL LIMESTONE
R-19	0' - 8' 8' plus	TILL, sandy and silty LIMESTONE
R -20	0' - 5' 5' plus	TILL, sandy, silty LIMESTONE
R-21	0' - 2' 2' - 4' 4' - 6'	GRAVEL, and very coarse sand outwash TILL SAND & GRAVEL, poorly sorted

MAP SYMBOL	SUMMARY OF DATA	
R-22	0' - 1.5' 1.5'-36.5'	GRAVEL, silty TILL
R-23	0' - 3' 3' - 6'	GRAVEL TILL
R-24	0' - 9' 9' -10' 10' -19'	GRAVEL, sandy, unsorted BOULDERS TILL
R-25	0' -10' 10' plus	SAND & GRAVEL, large boulders at surface SHALE & LIMESTONE
R-26	0' - 6.5'	SILT, frozen after 1.5', Vx and Vr
R-27	0' - 0.67' 0.67'-25'	SILT TILL
R-28	0' - 4' 4' plus	SILT GRAVEL, sandy
R-29	0' - 1' 0' - 2.5'	SILT TILL
R-30	0' -20'	SILT
R-31	0' -13' 13' -15' 15' -35'	SILT & SAND, lacustrine SAND & GRAVEL TILL, many shale inclusions
R-32	0' -40'	TILL
R-33	0' - 5' 5' plus	SAND & SILT GRAVEL
R-34	0' -30' 30' plus	SILT, lacustrine TILL
R-35	0' - 2' 2' -10' 10' plus	SAND & GRAVEL SILT SHALE
R-36		SAND, 20' eolian dunes, separated by organic zones frozen at 2.5'
R-37	0' - 2' 2' - 5' 5' plus	SILT SILT & SAND SAND
R-38	0' - 4'	SILT & CLAY, numerous boulder inclusions

MAP SYMBOL		SUMMARY OF DATA
R-39	0' -10' 10' -30'	TILL, silty SHALE
R-40	0' - 3' 3' - 4' 4' -10' 10' plus	CLAY, silty BOULDERS TILL, silty TILL, gravelly
R-41	0' - 4' 4' plus	SILT TILL
R-42	0' - 5' 5' -10' 10' plus	SILT TILL SHALE & LIMESTONE
R-43	0' - 1' 1' plus	SILT, sandy TILL
R-44	0' - 1' 1' plus	TILL LIMESTONE
R-45	0' -40'	SAND & GRAVEL
R-46	0' - 0.67' 0.67' plus	SILT, oxidized TILL, gravelly
R-47	0' - 2' 2' -22'	SILT TILL, gravelly
R-48	0' - 3' 3' - 4'	SILT, clayey TILL
R-49 gravel pit	0' - 5' 5' -12'	SAND, fine TILL, sandy (sand 46.2%, silt 27.6%, clay 26.2%)
R-50	0' -15' 15' -23'	GRAVEL, sandy TILL
R-51	0' -10' 10' -90'	SILT TILL, silty, disappears in boulders in creek bed
R-52	0' - 8' 8' -13'	TILL, sandy TILL
R-53	0' - 5' 5' -10' 10' plus	SAND TILL SHALE

MAP SYMBOL		SUMMARY OF DATA
R-54	0' -10' 10' -30'	SILT, lacustrine (sand 29.4%, silt 24.8%, clay 45.8%) GRAVEL, glaciofluvial
R-55	0' - 1' 1' -11'	SAND GRAVEL, poorly sorted with a high percentage of coarse sand
R-56	0' -19'	SAND
R-57	0' - 3' 3' - 4' 4' - 5' 5' - 8'	CLAY, silty SAND & SILT CLAY & SAND SAND & GRAVEL
R-58	0' -20' 20' plus	TILL SHAPE
R-59	0' - 2' 2' -10'	SAND GRAVEL
R-60	0' - 3' 3' -21'	SAND, fine SAND, medium to fine
R-61	0' - 2' 2' - 5' 5' - 7'	TILL SILT, sandy SAND
R-62	0' - 4' 4' -10'	SAND & SILT SAND
R-63	0' -18' 18' -22'	SAND & SILT SAND
R-64	0' - 2' 2' - 4'	SILT TILL
R-65	0' - 0.5' 0.5' plus	SILT TILL
R-66	0' -10' 10' plus	SAND, very fine GRAVEL
R-67	0' -40' 40' plus	TILL, silty SHAPE
R-68	0' -20'	SILT
R-69	0' -13'	SAND
R-70	0' -20' 20' -35'	SILT TILL

MAP SYMBOL

SUMMARY OF DATA

R-71	0' - 4' 4' plus	SAND TILL
R-72	0' - 4' 4' plus	SAND TILL
R-73	0' - 4' 4' plus	SILT TILL

MAP SYMBOL
(date drilled)

FROST AND
MOISTURE DATA

LITHOLOGY AND
ENGINEERING DATA

R-74 (9/6/72)	unfrozen to 0.5' Vx, Vr and Vs increasing to 50% by volume at the base frozen frozen frozen frozen to 18.3', unfrozen and moist to 19.3'	0' -12.3' BOG 12.3'-14.7' CLAY, silty 14.7'-15.8' ICE, some clay in cracks 15.8'-16.3' CLAY, silty 16.3'-19.3' SAND, coarse, becoming finer with depth
R-75 (13/6/72)	unfrozen to 1', Vx, Vr and Vs, increasing down- ward frozen Vs	0' -12' BOG 12' -16' CLAY, organic 16' -20.5' TILL, clayey
R-76 (20/6/72)	unfrozen to 2', Vx, Vr and Vs, increasing downward frozen, ice lenses up to 2" thick, approximately 50% ice by volume	0' - 8.8' BOG 8.8'-10.5' TILL, clayey
R-77 (21/6/72)	unfrozen to 0.5', Vx and Vr Vs	0' - 6.5' BOG 6.5'- 7.5' TILL, clayey
R-78 (17/6/72)	unfrozen to 0.3' Vx, Vr, Vs and ice increasing to 75% downward banded ice content, 80%	0' -27.3' BOG 27.3'-27.8' CLAY, silty and very organic

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
R-79 (18/6/72)	unfrozen to 0.7' Vx, Vr and Vs increasing to 25% downward, unfrozen between 16" and 17" (extent of active zone) frozen, banded ice	0' -19' BOG 19' -19.8' SILT

MAP SYMBOL	SUMMARY OF DATA
R-80	SANDSTONE
R-81	0' -50' TILL, gravelly 50' -51.5' SAND 51.5'-91.5' SILT, clayey

analysis as follows:

	SAMPLE	DILATENCY	TOUGHNESS	DRY STRENGTH	%<#4 SIEVE
	till	S	M	H	12%
	sand	Q	L	L	50%
	silt	S	M	H	---
R-82	0' -30'		GRAVEL, inclusions up to 1 metre present (gravel 47%, sand 47.3%, silt and clay 5.1%) DILATENCY - Q, TOUGHNESS - NONE, DRY STRENGTH - L		
R-83	0' -15'		GRAVEL		
R-84	0' - 0.5' 0.5'-plus		TILL, cemented, slope very steep, (> 40°) TILL, slope as above		
R-85	0' -55' 55' plus		TILL, (gravel 19.1%, sand 49.5%, silt and clay 31.4%, Pw=23.5%, Lw=34.2%) SAND & GRAVEL (gravel 63.7%, sand 26.8%, silt and clay 9.5%)		

	SAMPLE	DILATENCY	TOUGHNESS	DRY STRENGTH
	till	S	M	M
	sand & gravel	M	L	L

MAP SYMBOL

SUMMARY OF DATA

R-86	0' -10'	SILT
	10' -40'	SAND & GRAVEL (gravel 21%, sand 72.4%, silt and clay 6.6%)

R-87 SAND interbedded with SILT & CLAY,
lacustrine

SAMPLE	DILATENCY	TOUGHNESS	DRY STRENGTH	%<#4 SIEVE
silt	Q	M	L	100
	(sand 5.7%, silt and clay 94.3%)			
clay	NONE	H	H	100
	(sand 0.3%, silt and clay 99.7%)			

R-88	0' -10'	SILT
	10' -150'	SAND & SILT, lacustrine, unstable, (sand 90.3%, silt and clay 9.7%)

R-89	0'	-10'	SILT
	10'	-13'	SAND & GRAVEL
	13'	-33'	TILL

R-90	0' - 4'	SILT
	4' - 8'	SAND & GRAVEL
	8' - 13'	TILL

R-91	0'	-15'	TILL (gravel 12.4%, sand 21.2%, silt and clay 66.4%, Pw=20.4%, Lw=37.0%)
	15'	-21'	SAND, variable thickness 3' to 10'
	21'	-40'	TILL (gravel 13.6%, sand 31.9%, silt and clay 54.4%, Pw=18.2%, Lw=35.1%)

SAMPLE	DILATENCY	TOUGHNESS	DRY STRENGTH
upper till	S	M	H
lower till	NONE	H	H

R-92	0'	-15'	CLAY, lacustrine, silty (sand 20%, silt and clay 80%, Pw=28.6%, Lw=61.2%), unfrozen
	15'	-40'	SAND, fine to medium, unfrozen, slumping badly

R-93	0' -20'	TILL, oxidized, 5% to 15% inclusions, (gravel 36.7%, sand 24.8%, silt and clay 38.5%, Pw=14.2%, Lw=21.0%)
	20' plus	SAND & GRAVEL (gravel 30%, sand 70%)

R -94	0' - 2'	SILT
	2' - 3'	GRAVEL
	3' - 33'	TILL, stony (gravel 21.5%, sand 26.4%, silt and clay 52.1%)

MAP SYMBOL	SUMMARY OF DATA
R-95 0' -30'	TILL, silty and clayey, no ice and appears unfrozen, slumping very badly
R-96	ESKER (gravel 76.3%, sand 21.1%, sand and silt 1.6%)
R-97	TILL, four ridges, sampled one only, (gravel and sand 29.9%, silt and clay 70.1%)
R-98	SAND, eolian dune, (gravel 0.2%, sand 91.4%, silt and clay 3.5%)
R-99 0' - 5' 5' -15' 15' -30' 30' -50'	SILT, numerous boulders SAND, coarse with silt bands SAND, coarse with pebbles (gravel 13.6%, sand 77.0%, silt and clay 9.4%) SLUMP
R-100 0' - 6' 6' -14' 14' -20'	SILT, boulders and some clay bands TILL TILL, gravelly, in one place a 4' zone of gravel sampled (gravel 80.3%, sand 19.3%, silt and clay 0.2%)
R-101 0' -20'	TILL, silty to (very fine) sandy, (sand 1.2%, silt 44.6%, clay 54.2%)
R-102 0' -50'	TILL (sand 34.2%, silt 31.0%, clay 34.8%)
R-103 0' -40' 40' -50'	TILL (sand 34.2%, silt 31.0%, clay 34.8%) SAND & GRAVEL
R-104 0' -30'	SILT, lacustrine (sand 19.7%, silt and clay 80.4%)
R-105	GRAVEL & SAND (gravel 56%, sand 44.1%, silt and clay 2.0%)
R-106	GRAVEL, glaciofluvial (gravel 80.7%, sand 16.9%, silt and clay 1.7%)
R-107 0' -20'	TILL (gravel 15.0%, sand 36.4%, clay and silt 48.0%)
R-108	SAND, lacustrine (sand 91.3%, silt and clay 8.4%)
R-109	GRAVEL interbedded with SAND, glaciofluvial, both sampled gravel (gravel 72.6%, sand 23%, silt and clay 4.4%), sand (gravel 0.6%, sand 97.4%, silt and clay 1.7%)

MAP SYMBOL

SUMMARY OF DATA

R-110		TILL (gravel 9.6%, sand 32.3%, silt and clay 58.1%)
R-111	0' -20'	TILL (sand 28.2%, silt 33.6%, clay 38.2%)
R-112	0' -15'	TILL, clayey (sand 22.8%, silt 31.2%, clay 46%)

10.4 AREA III

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-1 (22/11/69)	frozen to 1', unfrozen with free water to 2' Nbn	0' - 2' ORGANIC 2' -15' TILL, clayey, large granite floats
C-2 (21/11/69)	unfrozen with free water to 9', Nbn to 15', w=12% @ 11'	0' - 1' ORGANIC 1' -15' SILT, clayey
C-3 (21/11/69)	Nbn, w=12% @ 6', w=12% @ 11'	0' - 1' ORGANIC 1' -15' SAND, silty, gravelly
C-4 (21/11/69)	Nbn, w=41% @ 6', w=29% @ 11'	0' - 1' ORGANIC 1' -15' CLAY, (52%, silty 48%) organic, Pw=58%, Lw=31% @ 6'
C-5 (21/11/69)	frozen frozen, w=3% @ 4' Nbn, w=28% @ 7' Nbe, w=21% @ 10'	0' - 3' ORGANIC 3' - 5' SILT, clayey, organic 5' -10' CLAY, silty, organic, trace of sand 10' -15' SAND, medium to fine
C-6 (3/11/70)	unfrozen to 2', Vx and Vr to 15', w=1,340% @ 3', w=935% @ 6' Vx and Vr, w=67% @ 21' w=28% @ 26' Nbn, w=21% @ 31'	0' -15' BOG, d=5 & 52 lbs/cu.ft. @ 6' 15' -30' SILT (54%, sand 23%, clay 23%) becoming sandier with depth zone of coarse sand 25.5' - 26', d=66 & 112 lbs/cu.ft. @ 21' 30' -32' TILL, sandy, gravelly
C-7 (3/11/70)	unfrozen unfrozen, w=14% @ 3' w=11% @ 6', w=9% @ 11', w=8% @ 15', w=13% @ 21'	0' - 0.25' ORGANIC 0.25'-22' TILL (gravel 12%, sand 32%, silt 40%, clay 16% trace of organics to 5', gravel becomes coarse below 15')
C-8 (3/11/70)	unfrozen Vx, w=45% @ 3' Nbn, w=28% @ 6', w=23% @ 10', w=23% @ 15', w=23% @ 20'	0' - 2' ORGANIC 2' - 5' SILT, clayey (33%), d=80 & 116 lbs/cu. ft., Pw=20%, Lw=36% @ 3' 5' -22' TILL, (gravel 28%, sand 30%, silt 24%, clay 18%)

MAP SYMBOL	SUMMARY OF DATA
S-1 0' - 45'	TILL, sandy and gravelly, often distinct zones of sand and gravel or gravel. Shale bedrock is encountered at between 25' and 30' at both ends of the line, but is more extensive in the east end. A clay cap of 10' is observed near the intersection with the winter road.
S-2 0' - 45'	TILL, sandy, slightly east of the midpoint zones of pure sand and clay observed. No bedrock encountered.
S-3 0' - 20' 20' - 45'	TILL, sandy and gravelly, makes up the entire section in the extreme west. Thick clay zones in the east. SHALE, outcrops near the midpoint.
S-4 (north of S-3) 0' - 45'	TILL, sandy and gravelly, often distinct zones (10') of sand or gravel and less frequently clay. Bedrock encountered in only one hole at 30'.
(south of S-3) 0' - 25' 25' - 45'	TILL, sandy and gravelly, clayey only at the intersection of the Rabbitskin River SHALE
S-5 0' - 25'	TILL, sandy and gravelly, trace of clay in the east only
S-6 0' - 25'	TILL, sandy and gravelly
S-7 0' - 60'	TILL, sandy and gravelly, in the extreme north the top 20'-30' is clay, gravel or sand and gravel
S-8 (west of S-7) 0' - 40' 40' - 60'	TILL, sandy and gravelly SHALE, dipping eastward
(east of S-7) 0' - 60'	TILL grading quickly from sandy to silty with distinct clay zones near the river. Thick permafrost associated with this clay.
S-9 0' - 15' 15' - 40'	SAND, becoming clayey at both ends TILL
S-10 (west of S-15) 0' - 45'	TILL, very sandy
(east of S-15) 0' - 20' 20' - 45'	TILL, gravelly SHALE encountered at between 15' and 30'
S-11 0' - 15' 15' - 45'	TILL, very sandy SHALE, outcrops near the midpoint
S-12 (west of S-14) 0' - 10' 10' - 40'	SAND CLAY

MAP SYMBOL

SUMMARY OF DATA

(east of S-14)	0' - 20'	TILL, sandy and gravelly
	20' - 40'	SHALE
S-13		
(west of S-15)	0' - 30'	TILL, very sandy, thick organic cover in extreme west
	30' - 40'	SHALE
(east of S-15)	0' - 20'	TILL, sandy, up to 25' of organics, permafrost observed in some holes
	20' - 40'	SHALE
S-14		
(south of S-9)	0' - 40'	SAND, except in north where shale outcrops
(north of S-9)	0' - 40'	TILL
S-15	0' - 25'	TILL, sometimes very sandy, up to 40' in extreme south
	25' - 40'	SHALE
S-16	0' - 15'	TILL, very sandy and gravelly
	15' - 40'	SHALE
S-17		
(west half)	0' - 40'	TILL
	40' - 50'	SHALE, dips gently to the west
(east half)	0' - 12'	ORGANIC
	12' - 25'	TILL, becoming increasingly gravelly eastward
	25' - 50'	SHALE, rising steadily in sections moving eastward
S-18	0' - 25'	TILL
	25' - 50'	SHALE
S-19	0' - 10'	CLAY, SILT, SAND & GRAVEL
	10' - 45'	TILL, sand, sometimes replaced by silt and clay near the centre of the line. Shale was encountered in several holes but there is no pattern
R-1	0' - 20'	SILT, lacustrine
	20' - 40'	TILL
	40' - 55'	GRAVEL
R-2	0' - 4'	SAND, lacustrine, large amount of silt
	4' - 19'	SAND, as above only numerous ice rafted boulders
R-3	0' - 4'	SILT, lacustrine
	4' - 24'	TILL, silty and sandy
	24' - 28'	SAND, fine, pebbles
	28' - 45'	SAND & GRAVEL

MAP SYMBOL		SUMMARY OF DATA
R-4	0' - 4' 4' - 24' 24' plus	SILT, lacustrine TILL, silty GRAVEL, variable thickness, pinching out, rests on shale
R-5	0' - 25' 25' - 60'	SAND SILT, lacustrine
R-6	0' - 10' 10' - 14' 14' - 24' 24' plus	TILL, silty and sandy GRAVEL TILL SHALE
R-7	0' - 4'	SILT, lacustrine
R-8	0' - 1' 1' - 2.5' 2.5' - 2.83' 2.83' - 4.0'	ORGANIC SAND, medium ORGANIC CLAY & SILT, occasional lens of coarse sand
R-9	0' - 20'	SAND, fine, very well drained
R-10	0' - 200' 200' plus	SAND, numerous gravel lenses, crossbedded SHALE
R-11	0' - 40' 40' - 80'	SAND SILT & CLAY
R-12	0' - 3' 3' plus	SILT, clayey, variable thickness SAND
R-13	0' - 10' 10' - 15' 15' - 200'	SAND & GRAVEL TILL, silty and clayey (sand 10.2%, silt 41.0%, clay 48.8%) GRAVEL & SAND
R-14	0' - 7' 7' plus	TILL SHALE
R-15	0' - 1' 1' - 11' 11' plus	SILT TILL SHALE
R-16	0' - 5' 5' - 6' 6' - 11'	TILL, clayey SAND, fine to medium TILL, sandy, pebbles and cobbles
R-17	0' - 6' 6' - 7' 7' plus	SILT, lacustrine, a few ice rafted boulders GRAVEL, stratified, sandy TILL, silty

MAP SYMBOL	SUMMARY OF DATA
R-18 0' - 20' 20' - 21' 21' - 27'	SAND, silty to very fine, a few pebbles GRAVEL SAND, very fine
R-19 0' - 30'	SAND, very fine, eolian dune parallel to the shoreline
R-20 0' - 20'	SAND, very fine, eolian dune as above
R-21 0' - 4' 4' - 14'	ORGANIC TILL
R-22 0' - 20'	TILL
R-23 0' - 15' 15' - 25'	SILT, lacustrine, ice rafted boulders TILL, sandy silty
R-24 0' - 5' 5' plus	TILL GRAVEL
R-25 0' - 25' 25' - 40' 40' - 50'	SAND, very fine GRAVEL, coarse, boulders common GRAVEL
R-26 0' - 20'	SAND, slumped in the western part
R-27 0' - 10'	SAND interbedded with SILT
R-28 0' - 80'	SAND, fine to medium, pebbles and cobbles in the upper few feet
R-29 0' - 15'	SAND interbedded with SILT, lacustrine
R-30 0' - 15'	SAND, very fine
R-31 0' - 20'	SAND & SILT, recent fluvial, numerous organic horizons
R-32 0' - 1' 1' - 5'	SILT, lacustrine TILL
R-33 0' - 15' 15' plus	TILL SHALE
R-34 0' - 15' 15' plus	TILL SHALE
R-35 0' - 15' 15' plus	TILL SHALE
R-36 0' - 45' 45' plus	TILL, silty SHALE

MAP SYMBOL

SUMMARY OF DATA

R-37		TILL, silty
R-38	0' - 2'	TILL, silty and clayey
R-39	0' - 15'	TILL (gravel 12.4%, sand 21.2%, silt and clay 66.4%, Pw=20.4%, Lw=37.0%)
	15' - 25'	SAND
	25' - 45'	TILL (gravel 13.6%, sand 31.9%, silt and clay 54.4%, Pw=18.2%, Lw=35.1%)
R-40		repeat of T-9
R-41		repeat of T-10
R-42		repeat of T-8
R-43	0' - 20'	SILT & CLAY (gravel 4.3%, sand 14.9%, silt and clay 80.8%)
R-44	0' - 125'	SAND, gravelly (gravel 16.4%, sand 82.2%, silt and clay 2%)
R-45	0' - 25'	GRAVEL (93.4%, sand 5.9%, silt and clay 0.4%), glaciofluvial
R-46	0' - 40'	TILL (gravel 1.4%, sand 40.6%, silt and clay 57.9%, Pw=15.8%, Lw=28.1%), calcareous.
R-47	0' - 20'	TILL, stony with boulder inclusions, (matrix; gravel 12.3%, sand 47.8%, silt and clay 39.9%, Pw=14.5%, Lw=23.4%). (coarse fraction; gravel > 1.5"=3.6% gravel between 1.5" and .375"=94.6% gravel < .375"=1.5% coarse sand =0.2%)

10.5 AREA IV

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-1 (21/11/69)	frozen frozen, w=2% @ 4' Nbn, W=28% @ 8' Vx and Vr, w=20% @ 11'	0' - 3' 3' - 5' 5' -10' 10' -15' ORGANIC SILT, clayey CLAY, silty, sandy SAND, medium to fine
C-2 (21/11/69)	frozen w=16% @ 4.5', W=14% @ 11'	0' - 4.5' 4.5' -15' ORGANIC TILL
C-3 (21/11/69)	frozen, w=27% @ 6' Nbn, 2=15% @ 8'	0' - 6' 6' -18' BOG SILT, clayey, becoming sandy with depth
C-4 (21/11/69)	frozen unfrozen with free water to 6', Nbn to 10' w=11% @ 6', w=16% @ 7'	0' - 1' 1' -10' ORGANIC TILL (sand 52%, silt 30%, clay 18%), Pw=16%, Lw=23% @ 6'
C-5 (20/11/69)	frozen to 1', unfrozen with free water to 2' unfrozen to 10', Vx and 2' Vr to 15', w=12% @ 5', w=12% @ 8', w=59% @ 10', w=12% @ 14'	0' - 2' -15' ORGANIC TILL, clayey
C-6 (20/11/69)	unfrozen with free water Vx, Vr and Vs, w=14% @ 6', w=11% @ 8.5', w=16% @ 15'	0' - 4' 4' - 9.5' 9.5' -15' ORGANIC TILL GRAVEL, sandy, silty
C-7 (20/11/69)	Nbn, w=15% @ 5', w= 11% @ 8', w=16% @ 9' Nbn, w=6% @ 12'	0' - 0.8' 0.8' -10' 10' -15' ORGANIC TILL, trace of organics SILT, large amount of gravel
C-8 (20/11/69)	frozen Vx, Vr and Vs, w=82% @ 5', w=35% @ 8' Nbn, w=28% @ 10.5', w=21% @ 15'	0' - 1' 1' -10' 10' -15' ORGANIC SILT (70%, sand 8%, clay 22%), trace of organics, Pw=22%, Lw=32% @ 5' SAND, fine, trace of organics
C-9 (19/11/69)	frozen Nbn, w=6% @ 6', w=6% 11', w=7% @ 14'	0' - 1' 1' -15' ORGANIC SAND, gravelly
C-10 (19/11/69)	frozen Nbn, w=27% @ 6', w=30% @ 8', w=25% @ 15'	0' - 2' 2' -16' ORGANIC SILT

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-11 (19/11/69)	unfrozen unfrozen to 5', Nbn to 15' w=39% @ 5', w=27% @ 11'	0' - 1.5' ORGANIC 1.5'-15' CLAY, silty, soft to 5'
C-12 (16/11/69)	unfrozen Nbn, w=41% @ 3' Nbn, w=15% @ 9'	0' - 2' ORGANIC, clayey 2' - 8' CLAY, silty 8' -15' GRAVEL
C-13 (15/11/69)	unfrozen unfrozen to 7', Nbn to 13' Nbn, w=23% @ 13.5'	0' - 2' ORGANIC, clayey 2' -13' SILT, soft to 7' 13' -16' CLAY (53%, silt 42%, sand 5%) Pw=28%, Lw=49% @ 13.5'
C-14 (15/11/69)	unfrozen, w=42% @ 4' Vr and Vs Nbe, w=8% @ 10' Nbn, w=12% @ 12', w= 19% @ 15.5'	0' - 0.5' ORGANIC 0.5'- 5' CLAY, silty, soft 5' - 9' TILL, clayey 9' -11' GRAVEL 11' -16' SILT, sandy at top, becoming clayey with depth
C-15 (15/11/69)	Nbn, w=17% @ 5', w= 8% @ 11', w=18% @ 14'	0' - 0.5' ORGANIC 0.5'-15.0' GRAVEL, sandy, silty
C-16 (15/11/69)	unfrozen, free water unfrozen, w=29% @ 15'	0' - 8' FEN 8' -20' CLAY (50%, sand 5%, silt 45%), soft to firm, Pw=18%, Lw=34% @ 15'
C-17 (3/11/70)	unfrozen unfrozen to 5', Vx to 20', Nbn to 22', w= 18% @ 3' and 7', w= 13% @ 11' and 16', w=10% @ 21'	0' - 2' ORGANIC 2' -22' TILL (gravel 2%, sand 25%, silt 38%, clay 35%), rust stains, shale fragments between 15' and 20', d-116 & 134 lbs/cu.ft. @ 3', d-120 & 134 lbs/cu.ft. @ 16'
C-18 (3/11/70)	unfrozen Vx to 10', Nbn to 18' Vx to 22', w=25% @ 3', w=17% @ 6', w=15% @ 10' w=14% @ 16', w=23% @ 21'	0' - 2' ORGANIC 2' -22' TILL (gravel 11%, sand 29%, silt 25%, clay 35%), rust stains, d=108 & 126 lbs/cu.ft. @ 10', d=116 & 135 lbs/cu.ft. @ 21'
C-19 (2/11/70)	unfrozen, w=30% @ 4' w=31% @ 6' Nbn, w=16% @ 11', w=14% @ 16', w=13% @ 21'	0' - 9.5' CLAY (44%, sand 13%, silt 43%) organic (8.5%), Pw=23%, Lw=40% @ 4' 9.5 -22' TILL (gravel 14%, sand 46%, silt 40%), shale fragments

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-20 (31/10/70)	unfrozen, w=253% @ 0.3' 0' - 0.5' unfrozen to 2', Vx to 0.5'-22' 22', w=13% @ 3', w=19% @ 6', w=12% @ 11', w= 11% @ 15.5', w=9% @ 21'	ORGANIC TILL (sand 28%, silt 35%, clay 37%, rust stains, zone of cobbles and boulders 16' - 17', c=108 & 116 lbs/cu.ft. @ 15.5'
C-21 (29/10/70)	unfrozen, w=19% @ 3' 0' - 4.5' unfrozen, w=4% @ 6' 4.5'-10'	ORGANIC, very silty SAND & GRAVEL, subangular, trace of silt (5%), drilling halted at 10' due to severe caving conditions
C-22 (28/10/70)	unfrozen to 2', Vx 0' - 9.5' to 9.5', w=448% @ 4', w=830% @ 6' Vx and Vr to 16', Vx 9.5'-22' to 22', w=71% @ 11', w=50% @ 16', w=31% @ 21'	BOG SILT (44%, sand 34%, clay 22%), lacustrine Pw=28%, Lw=53% @ 11', d=58 & 96 lbs/cu.ft. @ 11', d=90 & 118 lbs/cu.ft. @ 21'
C-23 (28/10/70)	unfrozen to 5', Vx to 0' -10' 10', w=653% @ 3', w= 622% @ 6' Vr to 15.5', Vx to 22' 10' -22' w=128% @ 11', w=62% @ 16', w=39% @ 21'	BOG SILT (54%, sand 5%, clay 41%), lacustrine, shells found at 16', Pw=40%, Lw=60% @ 11', d=38 & 80 lbs/cu.ft. @ 11' d=77 & 106 lbs/cu.ft. @ 21'
C-24 (28/10/70)	unfrozen, w=550% @ 3' 0' - 5' Vx, w=28% @ 6', w=28% 5' -22' @ 11', w=27% @ 16', w= 30% @ 21'	BOG, soft SILT, clayey, lacustrine, Pw= 26%, Lw=46% @ 6', d=104 & 128 lbs/cu.ft. @ 6'
C-25 (25/10/70)	unfrozen, w=416% @ 0.3' 0' - 0.5' unfrozen to 3.5', Vx 0.5'-21.5' and Vr to 21.5', w=28% @ 6', w=13% @ 11', w=23% @ 16', w=25% @ 21'	ORGANIC TILL, silty d=110 & 124 lbs/cu.ft. @ 11', d=100 & 114 lbs/cu.ft. @ 16'
C-26 (27/10/70)	unfrozen to 3', Vx and 0' - 3.5' Vr to 3.5', w=94% @ 3' Vx and Vr to 4', Vx to 3.5'-22' 10', Vx and Vr to 22' w=82% @ 7', w=62% @ 11', w=36% @ 16', w=29% @ 21'	ORGANIC SILT (clayey 13%, organic 18%), d=56 & 96 lbs/cu.ft. @ 7', d=100 & 126 lbs/cu.ft. @ 21'
C-27 (27/10/70)	unfrozen 0' - 1.5' unfrozen to 4.5', Vx 1.5'-10' to 10', w=29% @ 6' Vx, w=32% @ 11', w= 10' -22' 26% @ 16', w=28% @ 21'	ORGANIC CLAY, silty, Pw=27%, Lw= 48% @ 6', d=108 & 140 lbs/cu.ft. @ 6' TILL (gravel 2%, sand 4%, silt 45%, clay 49%), d=124 & 155 lbs/cu. ft. @ 16'

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-28 (24/10/70)	unfrozen, w=1215% @ 0.5' unfrozen, w=23% @ 5' Vr, w=22% @ 11', w=18% @ 16', ice content 5% by volume	0' - 0.7' ORGANIC 0.7'- 8' SILT, sandy 8' -17' TILL (gravel 5%, silt 40%, clay 54%), stiff when unfrozen, Pw=23%, Lw=49% @ 11', drilling halted at 17' due to excessive sloughing
C-29 (24/10/70)	unfrozen to 2', Vx and Vr to 3.5', w=217% @ 0.5', w=486% @ 3' Vx and Vr, w=82% @ 6', w=28% @ 11', w=27% @ 21'	0' - 3.5' ORGANIC, d=18 & 98 lbs/cu.ft. @ 3' 3.5'-21' SILT (clayey 18%, organic 6.1%), lacustrine, Pw=23%, Lw=32%, d=43 & 79 lbs/cu.ft. @ 6', Pw= 20%, Lw=27%, d=85 & 114 lbs/cu.ft. @ 15'
C-30 (24/10/70)	unfrozen, w=344% @ 0.5', w=180% @ 3' unfrozen to 4.5', Vs and ice lenses to 0.3' thick, w=349% @ 6', w=32% @ 11', w=60% @ 16', w=28% @ 21'	0' - 3' ORGANIC 3' -21.5' SILT (organic 6%), clayey (32% @ 16', 8% @ 21'); d=16 & 59 lbs/cu.ft. @ 6', Pw=20%, Lw=31% d=67 & 102 lbs/cu.ft. @ 16'
C-31 (30/10/70)	unfrozen, w=653% @ 0.5' unfrozen to 3.5', Vx to 10', w=59% @ 3', w=45% @ 6' Vx, w=33% @ 11', w=32% @ 16', w=32% @ 21'	0' - 0.5' ORGANIC 0.5'-10' SILT, organic 10' -22' TILL, silty, d=97 & 116 lbs/cu.ft. @ 11'
C-32 (30/10/70)	unfrozen, w=403% @ 0.3' unfrozen, w=25% @ 3' unfrozen, w=18% @ 6' w=13% @ 11', w=13% @ 16', w=12% @ 21'	0' - 0.3' ORGANIC 0.3'- 5' SILT (sand 8%, clay 28%), Pw=23%, Lw=34%, d=111 & 127 lbs/cu.ft. @ 3' 5' -22' TILL (gravel 4%, sand 19%, silt 49%, clay 28%)
C-33 (30/10/70)	unfrozen to 3', Vx and Vr to 4', w=139.8% @ 3' Vx and Vr, w=80% @ 6', w=37% @ 11' Vx and Vr Vx and Vr, w=18% @ 16', w=12% @ 21'	0' - 4' ORGANIC 4' -14' SILT, trace of fine sand, d=45 & 80 lbs/cu.ft. @ 6', d=86 & 117 lbs/cu.ft. @ 11' 14' -15' GRAVEL 15' -22' TILL (gravel 20%, sand 26%, silt 45%, clay 9%), d=116 & 134 lbs/cu.ft. @ 16'

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
C-34 (30/10/70)	unfrozen, w=656% @ 0.5' 0' - 2' unfrozen to 3.5', Vx 2' - 8' and Vr to 8', w=26% @ 3', w=24% @ 6', Nbn, w=10% @ 11', w=7% 8' -22' @ 16', w=8% @ 21'	ORGANIC SAND (gravel 2%, silt 18% to 40%) TILL, trace of gravel, d=140 & 151 lbs/cu.ft. @ 16'
C-35 (31/10/70)	unfrozen to 2', Vx 0' - 4' to 4', w=496% @ 3' Vx to 9', Nbn to 30', 4' -30' w=90% @ 6', w=25% @ 11', 2=23% @ 21'	ORGANIC SILT (sand 19%, clay 15%, organic 7.3%, below 9' sand content rises to 28%), lacustrine, d=51 & 97 lbs/cu.ft. @ 6'
C-36 (1/11/70)	unfrozen, w=715% @ 6.5' 0' - 2' Vx and Vr to 15', Vx 2' -34' to 34', w=41% @ 3', w=26% @ 6', w=31% @ 11', w=50% @ 16', w= 27% @ 21', w=29% @ 26'	ORGANIC, soft SAND (46%) & SILT (40%, clay 14%) clay content rises below 15', lacustrine, d=66 & 94 lbs/cu.ft. @ 3', d=64 & 97 lbs/cu.ft. @ 16'
C-37 (1/11/70)	unfrozen, w=291% @ 0.5' 0' - 1' unfrozen to 3', Vx to 1' -22' 10', Nbn to 22', w=12% @ 3', w=12% @ 6', w=8% @ 11', w=9% @ 16', w= 8% @ 21'	ORGANIC, soft TILL (gravel 20%, sand 38%, silt 24%, clay 20%)
C-38 (31/11/70)	unfrozen, w=239.8% @ 0' - 0.5' 0.5' unfrozen, w=24% @ 3' 0.5'- 4.5' unfrozen, w=20% @ 6', 4.5'-20' w=10% @ 11', w=8% @ 16'	ORGANIC SILT (sand 26%), soft SAND (silt 19%), very fine
C-39 (1/11/70)	unfrozen, w=408.5% @ 0' - 2' 0.5' Ice and silt 2' - 2.3' Vx, w=99% @ 3' 2.3'-5' Vx, w=17% @ 6', w=11% 5' -22' @11', w=6% @ 16', w=9% @ 21'	ORGANIC, soft ICE, silt lenses SILT (clay 15%, organic 5.9%), d=38 & 78 lbs/cu.ft. @ 3' TILL, trace of gravel, Pw=14% Lw=23%, d=144 & 152 lbs/cu.ft. @ 16'
C-40 (2/11/70)	unfrozen 0' - 2' Vx, w=48% @ 2', w=20% 2' -15' @ 6', w=26% @ 11' Vx, w=25% @ 16', w=20% 15' -22' @ 21'	ORGANIC, soft SAND (47%) & SILT (43%, clay 10%, d=66 & 99 lbs/cu.ft. @ 2' SAND (silt 29%), d=85 & 117 lbs/ cu.ft. @ 16'
C-41 (2/11/70)	unfrozen 0' - 2' Vx and Vr, w=24% @ 3' 2' - 5' Vx to 10', Nbn to 27', 5' -27' w=22% @ 11', w=25% @ 16' w=24% @ 21', w=20% @ 26'	ORGANIC SILT & SAND, very fine, trace of organics SAND (silty 34%), trace of gravel at 22', d=86 & 103 lbs/cu.ft. @ 11'

MAP SYMBOL	SUMMARY OF DATA	
C-42	SANDSTONE	
C-43	SANDSTONE	
C-44	0' - 0.3' 0.3' - 21'	ORGANIC, unfrozen SAND, silty (11%), very loose and dry, unfrozen SILT, sandy, unfrozen SAND, silty and loose, unfrozen
C-45	0' - 150'	SILT, boulder inclusions, major slope failure no apparent source of water in the slope
C-46	SILT, 6' thaw banks on thermokarst lakes	
C-47	0' - 40' 40' - 50'	TILL CLAY, silty
C-48	0' - 125' 125' - 135' 135' - 165'	SAND & GRAVEL, slope failure through all of these zones TILL SAND & GRAVEL
C-49	0' - 3' 3' - 250'	TILL, sandy and silty SHALE, very badly weathered, recessive such that the till is slumping or exposed as an overhang
C-50	0' - 50'	TILL, sandy zones interbedded with clay zones
C-51	0' - 50'	TILL, silty, exposed in steep bluffs
C-52	0' - 4' 4' - 54'	TILL SAND, becoming gravelly with depth, 30% silt near the top
C-53	0' - 100'	TILL, major slump in lower 60'
C-54	0' - 160'	TILL, bank slopes at 40°
C-55	large area covered by an old stable slide, failure occurred from a height of 360' and measures 2,000' inland and 5,000' along the river	
C-56	0' - 480'	TILL, bank slopes at 35°, minor solifluction in process down the slope
C-57	0' - 520'	TILL, old slide area now stable and forested
C-58	0' - 60'	SAND & SILT, badly undercut and slumping
C-59	0' - 170' 170' - 250'	SILT SHALE, black weathered

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-1	frozen, ice* 51% @ 0.2' 0' - 0.2' frozen, ice 8% @ 6', 0.2'-28.0' 30% @ 7.5', 15% @ 9.8', unfrozen from 12'	ORGANIC TILL
P-2	frozen 0' - 1' Vx, ice 12% @ 2.5', 10% 1' - 6' @ 5.5' N and Vx, ice 25% @ 6' -13' 7', 22% @ 12' N, ice 2% @ 13.5', 8% 13' -35' @ 33'	ORGANIC TILL SILT, clayey TILL, gravelly
P-3	Vx 0' - 2' Vx, ice 31% @ 3' 2' - 3.5' Vs to 7', Nbn to 20', 3.5'-20' ice 24% @ 4', 5% @ 19'	ORGANIC TILL SAND & SILT, trace of clay
P-4	Vx 0' - 1.5' Vs to 7', Nbn to 14' 1.5'-14' ice 54% @ 3.8', 4% @ 7', 21% @ 10.5', 5% @ 13' Nbn 14' -20'	ORGANIC SILT, clayey, trace of sand TILL, gravelly at base
P-5	Vx to 2', Nbn to 7', 0' - 7' ice 8% @ 3' Nbn to 11', Nf to 20', 7' -20' ice 5% @ 11'	SILT, clayey, sandy SAND, traces of silt and clay
P-6	frozen to 2', unfrozen 0' -12' to 12' unfrozen 12' -20'	TILL SAND, silty, trace of clay
P-7	frozen to 5.5' (limit of active layer), 0' -20' unfrozen to 20'	TILL, silty, very silty and sandy zone between 10' and 11'
P-8	frozen 0' - 1' frozen to 2', unfrozen 1' - 2.5' to 2.5' unfrozen 2.5'- 8.5' unfrozen 8.5'-20'	ORGANIC SILT, organic TILL, silty, clayey SHALE
P-9	frozen 0' - 1' frozen to 8' (limit of active layer), unfrozen 1' -20' to 20'	SAND, silty TILL, silty
P-10	frozen to 2.5', un* 0' -11' frozen to 2.9', Vx and Vr to 10.7', ice to 11' Vx and Vr, ice 66% @ 11' -12.8' 12.7' frozen 12.8'-14' Vx 14' -20'	BOG SILT COBBLES & BOULDERS TILL, gravelly

*Estimated % of excess ice

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-11	N N N to 12' (limit of active layer), unfrozen to 18.5' N	0' - 3' ORGANIC, sandy 3' - 9' SAND & GRAVEL, cobbles 9' -18.5' TILL, boulders to 15', level, sandy, gravelly 18.5'-20' SILT, sandy
P-12	frozen frozen to 2.4', unfrozen to 20'	0' - 0.5' ORGANIC 0.5'-20' TILL, silty, clayey
P-13	frozen frozen frozen to 10.5' (limit of active layer), un- frozen to 16.5' unfrozen	0' - 1' ORGANIC 1' - 2' SAND, silty 2' -16.5' TILL, sandy, gravelly 16.5'-20' GRAVEL
P-14	frozen frozen frozen to 9', unfrozen to 20'	0' - 1' ORGANIC 1' - 3' SILT, sandy 3' -20' TILL, silty to 6.5', sandy, gravelly to 20'
P-15	frozen N N	0' - 0.5' ORGANIC 0.5'- 5.5' CLAY, silty 5.5'-10.0' TILL, sandy
P-16	frozen frozen to 2', unfrozen to 10' unfrozen	0' - 0.5' ORGANIC 0.5'-10' TILL 10' -18' SILT & CLAY, trace of sand
P-17	frozen unfrozen	0' - 2' ORGANIC 2' -13' SILT & CLAY, trace of sand
P-18	frozen frozen, ice 20% @ 3' frozen frozen to 12', unfrozen to 20'	0' - 1' ORGANIC 1' - 4' SAND, silty, trace of clay 4' - 7' TILL 7' -20' SHALE
P-19	frozen frozen unfrozen	0' - 0.2' ORGANIC 0.2'- 4' SAND, silty, trace of clay 4' -18' TILL, clayey, silty, cobbles
P-20	frozen frozen to 3', unfrozen to 17' unfrozen unfrozen	0' - 1' SILT, sandy 1' -17' TILL, gravelly 17' -21' GRAVEL, sandy 21' -24' TILL
P-21	frozen frozen to 1.8', un- frozen to 18.5' unfrozen	0' - 1' ORGANIC, sandy 1' -18.5' TILL, sandy 18.5'-20' GRAVEL, sandy

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-22	Ice unfrozen unfrozen	0' - 0.8' ICE 0.8'-10' FEN 10' -20' GRAVEL
P-23	Nbn Nbn Nbn	0' - 0.2' ORGANIC 0.2'- 2' SAND, silty 2' -20' SAND, traces of silt and clay
P-24	frozen frozen unfrozen	0' - 1' SAND 1' - 9' TILL, cobbles, sandy 9' -13' GRAVEL & SAND, cobbles
P-25	frozen Nf, ice 5% @ 3' Nf	0' - 2.5' ORGANIC, sandy, silty 2.5'- 7' SILT, sandy, trace of clay 7' -20' SAND, trace of silt and clay to 19'
P-26	frozen frozen to 3' (limit of active layer), unfrozen to 4', frozen to 20'	0' - 1' ORGANIC 1' -20' TILL, silty, clayey
P-27	frozen frozen to 1.5', Vs to 2.8' Vs to 3.5' (limit of active layer), ice 13% @ 3' N	0' - 0.8' ORGANIC 0.8'- 2.8' SILT, sandy 2.8'- 3.5' SAND, silty 3.5'-20' TILL, clayey
P-28	Nbn Nbn Nbn Vr to 11', Nbn to 11.3' Nbn to 15.1', Vx to 16.3', Nbn to 20', ice 6% @ 14.8', 20% @ 17'	0' - 1.7' SAND 1.7'-7' TILL, sandy 7' -10' SAND 10' -11.3' CLAY, sandy silty, distinct lenses of sand 11.3'-20' SAND trace of silt and clay zone of pure sand between 14' 15.1'
P-29	N N N Vx to 15' (limit of active layer), N to 18'	0' - 0.8' ORGANIC 0.8'- 6' TILL, sandy, gravelly 6' -12' SILT, SAND & CLAY 12' -18' SILT, clayey
P-30	frozen frozen, ice 9% @ 6', 4% @ 10', 5% @ 18'	0' - 4' ORGANIC, sandy, silty after 2' 4' -20' SILT, traces of clay and sand
P-31	frozen	0' - 9' TILL, gravelly, sandy

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-32	Vs Vs to 3', Vx to 7', N to 20', ice 33% @ 2.5', 7% @ 7', 12% @ 10', 2% @ 18.5'	0' - 0.3' ORGANIC 0.3'-20' CLAY & SILT, trace of sand
P-33	frozen frozen to 3', Vx to 6' N to 20', ice 23% @ 2', 36% @ 2.5', 3% @ 5.5'	0' - 0.5' ORGANIC 0.5'-20' CLAY & SILT
P-34	frozen frozen to 11.5', unfrozen to 20'	0' - 0.8' ORGANIC, silty 0.8'-20' SILT & CLAY, traces of sand and gypsum below 12.7'
P-35	frozen Vx to 10', Vx and Vs to 14', ice 8% @ 2.5', 2% @ 10' Vx and Vs	0' - 1' ORGANIC 1' -14' SILT & CLAY, trace of sand 14' -20' SAND & SILT, trace of clay
P-36	frozen frozen to 3', unfrozen to 12', saturated below 6'	0' - 1' ORGANIC 1' -12' TILL, sandy and gravelly
P-37	frozen frozen to 2', Vx to 20'	0' - 1.8' ORGANIC, silty below 0.3' 1.8'-20' SILT & CLAY
P-38	Vx Vx, ice 37% @ 2' Vx, ice 34% @ 3.5' Vx, ice 6% @ 6.5' 16% @ 10'	0' - 0.8' ORGANIC 0.8'- 3.5' SILT, clayey 3.5'- 3.8' ORGANIC 3.8'-20' CLAY & SILT, trace of sand
P-39	frozen frozen to 1.5' (limit of active layer), un- frozen to 3', frozen to 20', ice 7% @ 7', 3% @ 16', 3% @ 19'	0' - 1' ORGANIC 1' -20' CLAY & SILT
P-40	frozen frozen to 3', unfrozen to 10' unfrozen	0' - 0.5' ORGANIC 0.5'-10' SAND, silty, trace of clay below 6' 10' -15' TILL, gravelly, sandy, boulders
P-41	frozen to 1.5', unfrozen to 2' unfrozen	0' - 2' ORGANIC, sandy, silty 2' -13.5' TILL, sandy becoming gravelly with depth

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-42	frozen frozen to 4', unfrozen to 15'	0' - 0.3' ORGANIC 0.3'-15' CLAY, silty
P-43	frozen frozen to 3', unfrozen to 14'	0' - 0.3' ORGANIC 0.3'-14' TILL, sandy, gravelly, cobbles
P-44	N N to 5.5', Vx to 10', Vx and Vs to 20', ice 47% @ 3', 34% @ 9', 51% @ 12', 33% @ 14', 19% @ 19'	0' - 0.5' ORGANIC 0.5'-20' CLAY & SILT, trace of sand below 4'
P-45	frozen frozen to 6', unfrozen to 20'	0' - 0.3' ORGANIC 0.3'-20' SILT & CLAY, trace of sand
P-46	frozen frozen to 3.5', unfrozen to 4', ice 3% @ 3.5' unfrozen unfrozen	0' - 1.5' ORGANIC 1.5'- 4' CLAY, silty 4' - 5' SAND, clayey 5' -20' TILL, silty, clayey
P-47	frozen to 1.5', unfrozen to 2' unfrozen	0' - 2' ORGANIC 2' -20' CLAY, silty, trace of sand
P-48	frozen to 1.5', unfrozen to 3' unfrozen	0' - 3' ORGANIC 3' -19' TILL, silty, clayey
P-49	V V to 3', Vs to 4', Vr to 11', N to 15', Vx to 20', ice 11% @ 4', 15% @ 15', 21% @ 20'	0' - 1.3' ORGANIC, silty 1.3'-20' SILT & CLAY
P-50	Vx to 2', ice and peat to 2.8', Vx to 4', N to 4.5' Vs to 5.1', Vr to 15', Vx to 20', ice 6% @ 12', 35% @ 16', 9% @ 19'	0' - 4.5' ORGANIC 4.5'-20' CLAY & SILT, silt lenses to 5.5'
P-51	frozen, ice 7% @ 0.7' frozen to 15', Vx to 16', frozen to 28', unfrozen to 68' ice 7% @ 4', 15% @ 28'	0' - 0.8' CLAY, silty 0.8'-68' CLAY & SILT

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-52	frozen frozen	0' - 1.7' SAND, silty 1.7'-11' TILL, boulders
P-53	frozen frozen to 2', unfrozen to 11'	0' - 1' ORGANIC, sandy, silty 1' -11' TILL, gravelly, sandy
P-54	frozen frozen to 1', unfrozen to 15.5' unfrozen, saturated below 22'	0' - 0.3' ORGANIC 0.3'-15.5' CLAY, silty 15.5'-30' TILL, sandy
P-55	N N to 2.7', unfrozen to 20'	0' - 0.3' ORGANIC 0.3'-20' TILL, silty clayey
P-56	N N to 1.6', unfrozen to 1.8', Vs, Vx, Vr and N to 21.3', ice 30% @ 2', 17% @ 21'	0' - 1.4' ORGANIC 1.4'-21.3' SILT & CLAY, trace of sand below 20'
P-57	frozen frozen to 4', unfrozen to 20'	0' - 0.3' ORGANIC 0.3'-20' SILT & CLAY, traces of sand
P-58	frozen frozen, ice 43% @ 1.8' unfrozen unfrozen	0' - 0.3' ORGANIC 0.3'- 2.2' SAND, silty 2.2'- 5' GRAVEL, sandy 5' - 7' COBBLES & BOULDERS
P-59	N N, Vs and Vr to 6', Vs to 20', ice 25% @ 1.5', 2% @ 4', 10% @ 8', 4% @ 10'	0' - 0.5' ORGANIC 0.5'-20' SILT & CLAY, trace of sand
P-60	frozen frozen to 3.2', un- frozen to 16', frozen to 20'	0' - 0.7' ORGANIC 0.7'-20' SILT & CLAY, trace of sand and gravel
P-61	frozen frozen frozen to 11', un- frozen to 13'	0' - 1.5' ORGANIC, sandy, silty 1.5'- 6' TILL, sandy, trace of clay 6' -13' GRAVEL, sandy, traces of silt and clay
P-62	Vr Vr Vr Vr to 3.8', Vr and Vs to 5', Vs to 19', ice 19% @ 4', 4% @ 10'	0' - 0.7' ORGANIC, silty, clayey 0.7'- 2.5' CLAY, silty 2.5'- 2.8' ORGANIC 2.8'-19' SILT & CLAY, trace of sand

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-63	Vr and Vs Vs, Vx and Nbn, ice 18% @ 4', 6% @ 6' Nbn Vs to 14.8', N to 20'	0' - 2.5' ORGANIC 2.5'-12' SILT & CLAY, trace of sand 12' -13.6' SILT 13.6'-20' CLAY, silty, cobbles after 14.8'
P-64	Vs, ice 51% @ 1' Vs to 5', Nbn to 7' Vs to 20'	0' - 1.8' ORGANIC 1.8'-20' SILT & CLAY traces of sand and gravel
P-65	Ice frozen to 4.5', unfrozen and saturated to 20'	0' - 0.8' ICE 0.8'-20' GRAVEL, sandy, trace of silt and clay, cobbles and boulders
P-66	frozen frozen to 6', unfrozen to 20'	0' - 2.2' ORGANIC 2.2'-20' SILT, sandy, clayey
P-67	Vr Vr to 3.5', unfrozen to 9.5', Vs to 15', Vr to 20', ice 8% @ 3.5', 4% @ 15', 3% @ 16'	0' - 1' ORGANIC 1' -20' SILT, clayey, sandy
P-68	Vr Vr Vr unfrozen to 8', N to 20', ice 5% @ 9', 7% @ 16', 5% @ 18'	0' - 2' ORGANIC 2' - 2.5' CLAY 2.5'- 2.8' ORGANIC 2.8'-20' CLAY & SILT, trace of sand
P-69	frozen frozen to 1', Vs to 5' Vr to 10', Vx to 20', ice 18% @ 6', 3% @ 9', 4% @ 19'	0' - 0.3' ORGANIC 0.3'-20' CLAY, silty
P-70	frozen to 2', unfrozen to 20', ice 33% @ 2'	0' -20' SILT, sandy, clayey
P-71	frozen Vs to 10', N to 20', ice 20% @ 2.5', 6% @ 9', 3% @ 13', 24% @ 18'	0' - 0.8' ORGANIC 0.8'-20' CLAY, silty, traces of sand and gravel
P-72	Vs Vs to 10', N to 20', ice 40% @ 4', 7% @ 9'	0' - 2.5' ORGANIC 2.5'-20' CLAY, silty, traces of sand and gravel

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-73	Vs Vr and Vs Vr and Vs to 8', Vs to 10', N to 16', Vx to 20' ice 22% @ 5.5', 4% @ 13', 7% @ 19'	0' - 4' ORGANIC 4' - 4.8' SILT 4.8'-20' CLAY & SILT, traces of sand and gravel
P-74	frozen frozen to 2', unfrozen to 11.5', frozen to 20', ice 18% @ 16', 3% @ 19'	0' - 0.8' ORGANIC 0.8'-20' CLAY, silty, coarse gravel below 10'
P-75	Vx, ice 8% @ 1' Vx to 10', N to 15', Vx to 17', N to 20', ice 24% @ 9.5', 5% @ 14', 16% @ 16', 12% @ 19'	0' - 1' CLAY, silty 1' -20' SILT, clayey
P-76	Vx Vs to 4.4', Vs to 4.6', N to 19', Vx and Vs to 20', ice 8% @ 3', 43% @ 19'	0' - 0.9' ORGANIC, sandy, silty 0.9'-20' CLAY, silty, traces of sand and coarse gravel
P-77	Vx Vx to 4', unfrozen to 20', ice 28% @ 4'	0' - 3' ORGANIC 3' -20' CLAY, silty
P-78	Vs Vs, ice 29% @ 2', 9% @ 3' Vs to 13', N to 17.5', Vx to 20', ice 6% @ 8', 4% @ 10'	0' - 2' ORGANIC 2' - 4.2' SILT, clayey, trace of sand 4.2'-20' CLAY, silty, traces of sand and coarse gravel
P-79	Vx Vx, ice 19% @ 3' Vx Vx	0' - 0.5' ORGANIC 0.5'- 8' CLAY, silty, traces of sand and gravel 8' -10' CLAY & SAND, silty, varved 10' -20' CLAY, silty, traces of coarse gravel
P-80	frozen frozen, ice 16% @ 1' Vx Vx Vx to 6', N to 20'	0' - 0.5' ORGANIC 0.5'- 2' CLAY, silty 2' - 2.5' GRAVEL & COBBLES 2.5'- 4' SAND, gravelly 4' -20' SILT, clayey, sandy, coarse gravel and cobbles
P-81	frozen Ice + silt Vx, ice 15% @ 3' N	0' - 1' ORGANIC, silty 1' - 1.8' ICE, silty 1.8'- 3.6' SAND & SILT 3.6'-20' TILL, sandy, gravelly

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-82	frozen frozen to 2.5', Vs to 7', ice 40% @ 3', 22% @ 6' Nbn Nbn, Vx and Vr, ice 4% @ 15'	0' - 0.7' ORGANIC, silty 0.7' - 7' SILT & CLAY, trace of sand 7' - 8.5' SILT, sandy, trace of clay 8.5' - 20' SILT & CLAY, trace of sand
P-83	frozen frozen to 2.3', un- frozen to 17', N to 20', ice 19% @ 1.5', 3% @ 7'	0' - 0.5' ORGANIC 0.5' - 20' SILT & CLAY, sandy
P-84	Nf, ice 45% at surface	0' - 20' SAND, silty, trace of clay, trace of coarse gravel above 10'
P-85	frozen Vs, ice 35% @ 3.8' Vs Vs, ice 3% throughout Nbn Vs, Vr, Vx and V, ice 9% @ 17', 17% @ 22', 8% @ 28'	0' - 1.5' ORGANIC, sandy 1.5' - 4.8' SAND, becoming silty and clayey downward 4.8' - 5' GRAVEL 5' - 10' CLAY, silty, sandy 10' - 16.5' SILT, sandy 16.5' - 30' CLAY, silty
P-86	frozen unfrozen unfrozen unfrozen unfrozen unfrozen unfrozen	0' - 4.5' SAND, gravelly, traces of silt and clay 3' - 4.5' BOULDERS 4.5' - 7' SAND, gravelly, traces of clay and silt 7' - 8' BOULDERS 8' - 9.5' SAND, GRAVEL & CLAY 9.5' - 11.5' BOULDERS 11.5' - 12' SAND, GRAVEL & COBBLES
P-87	frozen unfrozen	0' - 2' SAND 2' - 12' SAND & GRAVEL, some zones silty and clayey
P-88	Vr and Vs Vr and Vs Vr and Vs, ice 30% @ 3.8' Nbn Nbn, Vr, N and Vs Nbn Nbn, Vr, Vx and Vs Nbn Vr	0' - 2' ORGANIC, clayey 2' - 3.4' CLAY, silty 3.4' - 4' SILT 4' - 9' SILT, sandy, trace of clay 9' - 11.7' CLAY, silty 11.7' - 12' SILT 12' - 18' CLAY, silty 18' - 19' SILT 19' - 20.8' CLAY, silty

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
P-89	N N N to 10', Vx to 13.5' unfrozen	0' - 0.3' ORGANIC 0.3'- 4' SAND, clayey, trace of gravel 4' -13.5' CLAY & SILT, trace of gravel 13.5'-20' SAND & GRAVEL
P-90	Vs Vs to 5', Nbn to 6.5' ice 6% @ 2', 3% @ 4' Nbn Vx	0' - 0.3' ORGANIC 0.3'- 6.5' SILT, sandy, trace of clay 6.5'-13.3' CLAY, silty 13.3'-20' TILL
MAP SYMBOL	SUMMARY OF DATA	
T-1	This location represents three probes in close proximity	
hole 1	unfrozen to 0.9', frozen to 6.7', ice varies between 60% and 80% frozen, ice varies between 52% and 78%	0' - 6.7' PEAT POLYGON (centre of polygon) 6.7'- 8.5' TILL
hole 2	unfrozen Ice	0' - 3.3' PEAT POLYGON (on periphery of polygon on ice wedge) 3.3'- 4.7' ICE
hole 3	unfrozen Ice	0' - 1.3' PEAT POLYGON (on periphery of polygon on ice wedge) 1.3'- 3.2' ICE
T-2	This location represents three probes in close proximity	
hole 1	unfrozen to 1.5', frozen to 5', ice varies between 64% and 79% frozen, ice varies between 67% and 38%	0' - 5' PEAT PLATEAU 5' - 6.7' TILL
hole 2	unfrozen, saturated unfrozen	0' -10' FEN 10' -11.7' TILL
hole 3	unfrozen, saturated unfrozen	0' -12' FEN 12' -13.3' TILL

MAP SYMBOL

SUMMARY OF DATA

T-3	This location represents two probes in close proximity	
hole 1	unfrozen to 1', frozen to 11', ice + organic between 5' and 7.8' frozen	0' - 8.5' PALSAs, wooded 8.5'-10.1' TILL
hole 2	unfrozen, saturated unfrozen	0' - 8' FEN 8' - 9.5' TILL
S-1	(north south section)	0' -27' 27' -45' TILL SHALE
	(east west section)	0' -30' 30' -45' TILL, gravelly near the Willowlake River, thins westward to 10' SHALE
S-2	0' -45'	TILL, sandy and gravelly, near the Willowlake River crossings frequently the top 20' are sand and gravel
S-3	0' -45'	TILL, sandy and gravelly near the Willowlake River crossing, north of this crossing distinct zones of gravel are frequently encountered. Shale found in two holes north of the crossing at 20'
S-4	0' -45'	TILL, sandy and gravelly, shale outcrops in the northern half of the line
S-5	0' -45'	TILL, clayey, several thick gravel zones in the centre of the line, shale and sandstone outcrop in the north half of the line
S-6	0' -45'	TILL, clayey, several thick sand and gravel zones in the centre of the line, thick perma- frost at the intersection of S-2
S-7	(south of Willowlake River)	0' -45' TILL, sandy, gravelly, thick zones of gravel encountered at stream crossings, shale en- countered at 20' in the central part of the line
	(north of Willowlake River)	0' -45' TILL, sandy, gravelly, one hole in the extreme north encountered sandstone at 35'

MAP SYMBOL

SUMMARY OF DATA

S-8			
(south of Willowlake River)	0'	-45'	TILL, sandy, gravelly, permafrost noted through most of the swampy areas
(north of Willowlake River)	0'	-20'	GRAVEL & SAND
	20'	-45'	SHALE
S-9			VARIABLE, in the extreme east 25' of till over shale. From there to the centre of the line complete sections of sand, gravel or till becoming all till westward past the centre. In the extreme west 20' of clay containing permafrost over shale
S-10	0'	-45'	TILL, except in the centre where 20' of gravel rests on the till, isolated sandstone outcrops in the centre of the line
S-11	0'	-40'	TILL, frequently gravelly 0' - 20'
S-12	0'	-40'	TILL, except to the east of Ebbutt Hills where the holes are entirely sand and gravel
S-13	0'	-30'	TILL, clayey
	30'	-40'	SHALE, no shale encountered in the southwest end of the line
S-14	0'	-40'	TILL, sandy in the northwest and clayey in the southeast, also in the southeast shale encountered at 15'
S-15	0'	-45'	TILL, shale encountered at 35' in the south, in the north sand frequently encountered at 20'
S-16	0'	-45'	TILL, up to 35' of gravel over the till in the extreme north
S-17	0'	-40'	TILL, up to 40' of organics in the extreme west
S-18	0'	-10'	ORGANIC
	10'	-40'	TILL, frequently outcrops
S-19	0'	-10'	ORGANIC, frequently permafrost noted in this zone
	10'	-40'	TILL, frequently outcrops
S-20	0'	-40'	TILL, permafrost encountered in most of the holes
S-21	0'	-40'	TILL, random gravel caps up to 20' thick

MAP SYMBOL		SUMMARY OF DATA
S-22	0' -40'	TILL, several shale outcrops in the centre of the line
S-23	0' -40'	TILL, gravel cap of 20' in holes near the intersection of S-16, shale encountered at 10' in the extreme east
S-24	0' -40'	TILL, gravelly, 20' of gravel caps the sections near stream crossings
S-25	0' -20' 20' -40'	GRAVEL TILL, gravelly, frequently outcrops where gravel thins
S-26	0' -40'	TILL, frequently very sandy and gravelly in the upper 25', shale outcrops immediately west of the midpoint of the line. A deep hole on the extreme west end of the line showed the following section: 0' - 65' TILL 65' -105' GRAVEL
S-27	0' -40'	VARIABLE, random 20' zones of gravel, sand, gravel and sand, clay and shale in the southwest end at 20'
S-28		
(east half)	0' -40'	SAND & GRAVEL
(west half)	0' -40'	TILL
S-29		
(east half)	0' -50'	TILL, clayey, frequently sections are entirely clay
(west half)	0' -20' 20' -45'	TILL SHALE, frequently outcrops
S-30		
(straight portion)	0' -50'	CLAY, clayey till, numerous 20' gravel zones in the north
(curved portion)	0' -15' 15' -50'	CLAY & TILL, clayey SANDSTONE
S-31	0' -40'	TILL, up to 20' of gravel caps the sections where the line crosses the River Between Two Mountains and east of the topographic high in the eastern part of the line.
S-32	0' -40'	TILL
S-33	0' -40'	TILL, sandy, distinct sand and gravel zones near the lakes in the east

MAP SYMBOL

SUMMARY OF DATA

S-34	0'	-40'	TILL
S-35	0'	-40'	TILL, gravelly in the east
S-36	0'	-40'	TILL, gravelly at the stream crossings
S-37	0'	-50'	TILL or SHALE, till predominant in the east where there is frequently a clay cap up to 10'
S-38			
(south of S-39)	0'	-45'	TILL
(north of S-39)	0'	-45'	CLAY, includes two holes immediately south of S-39, till appears again in the extreme north with permafrost recorded within it
S-39	0'	-45'	TILL, random gravel caps up to 20' thick, shale encountered in the extreme east at 40'
S-40			
(eastern quarter)	0'	-45'	CLAY, clayey till, near the Johnson River the section is: 0' -15' SAND & GRAVEL 15' -45' TILL
(western quarter)	0'	-40'	SAND or CLAY or TILL
	40'	-80'	SHALE
(centre half)	0'	-50'	TILL, commonly a gravel cap of up to 30'
S-41			
(north of Johnson River)	0'	-50'	TILL, frequently distinct zones of sand, gravel or clay, sandstone outcrops at the centre of the line
(south of Johnson River)	0'	-10'	CLAY or TILL
	10'	-55'	SANDSTONE
S-42	0'	-45'	TILL, sandy, near the centre zones of sand up to 30' thick
S-43	0'	-45'	TILL, sandy, gravel caps up to 10' at stream crossings and entire sections of sand or gravel in the east near the Mackenzie River
S-44	0'	-45'	GRAVEL, SAND & CLAY, interbedded, till only at the extreme east end
S-45	0'	-45'	TILL, clayey, shale and sandstone found in several holes at 25'
R-1	0' - 1'		ORGANIC
	1' plus		TILL, permafrost at 1'
R-2	0'	-15'	TILL
	15' plus		SHALE

MAP SYMBOL	SUMMARY OF DATA
R-3 0' - 1' 1' - 5'	SILT, lacustrine TILL
R-4 0' -15' 15' plus	SILT, lacustrine SHALE
R-5 0' - 2'	SILT, clayey
R-6 0' -10' 10' -15' 15' -200'	SAND & GRAVEL TILL (sand 10.2%, silt 41%, clay 48.8%) GRAVEL & SAND
R-7 0' -30' 30' -60'	SAND TILL
R-8 0' - 3'	SILT, lacustrine, oxidized
R-9 0' - 0.5' 0.5' plus	GRAVEL SAND, fine to medium, small pebbles
R-10 0' -25' 25' plus	GRAVEL, alluvial fan SILT & SAND, lacustrine
R-11 0' -20' 20' -80'	SAND & GRAVEL TILL
R-12 0' -20' 20' plus	SAND & SILT, lacustrine TILL
R-13	TILL SHALE & LIMESTONE, outcrops in 150' cliff
R-14 0' -25' 25' -45'	SAND, lacustrine TILL (sand 42.2%, silt 28%, clay 29.8%)
R-15 0' -25' 25' plus	TILL, slumped LIMESTONE
R-16 0' -20' 20' plus	TILL LIMESTONE
R-17 0' - 5' 5' plus	TILL LIMESTONE
R-18 0' - 5' 5' plus	TILL LIMESTONE
R-19 0' -30' 30' plus	TILL GRAVEL, coarse, poorly sorted, becoming finer with depth

MAP SYMBOL		SUMMARY OF DATA
R-20	0' - 20' 20' plus	GRAVEL SHALE
R-21	0' - 1' 1' plus	ORGANIC, oxidized CLAY, pebbles
R-22	0' - 80'	SAND, fine to medium, many pebble inclusions
R-23	0' - 75' 75' - 100'	SAND, very fine SILT, clayey
R-24	0' - 2' 2' - 3' 3' - 5'	SILT & SAND, very fine ORGANIC SILT & SAND, very fine, as above
R-25	0' - 25'	GRAVEL & SAND, numerous boulders, ice push ridge
R-26	0' - 6' 6' - 10'	SILT & SAND, lacustrine, crossbedding in lower 2' GRAVEL & SAND, stratified
R-27	0' - 20' 20' - 35'	SILT & SAND TILL, gritty, silty, numerous boulders
R-28	0' - 1' 1' - 100'	SAND & SILT TILL
R-29	0' - 1.5' 1.5' - 21.5' 21.5' - 30' 30' - 37'	SAND, oxidized SAND & GRAVEL TILL SHALE, badly weathered
R-30	0' - 11' 11' - 13.5' 13.5' - 17.5' 17.5' - 18.5' 18.5' - 30' 30' - 36' 36' - 47'	TILL (gravel 14%, sand 35%, silt and clay 51%) SILT, several 1" organic zones CLAY, silty SAND & GRAVEL SAND, coarse, thin silt bands SAND, coarse, silty SAND & GRAVEL, fine, interbedded
R-31	0' - 45' 45' plus	GRAVEL & SAND TILL
R-32	0' - 1' 1' plus	ORGANIC TILL (gravel 13.5%, sand 32.9%, silt and clay 53.6%)
R-33	0' - 80'	SAND & GRAVEL
R-34	0' - 1' 1' plus	ORGANIC TILL (gravel 4.4%, sand 25.5%, silt and clay 69.9%)

MAP SYMBOL		SUMMARY OF DATA
R-35		TILL (gravel 7.5%, sand 25.6%, silt and clay 66.6%) hummocks separated by deep trenches
R-36	0' - 50'	SAND, silty, ridges
R-37	0' - 1' 1' plus	ORGANIC TILL (gravel 10.7%, sand 40.8%, silt and clay 48.3%)
R-38	0' - 1.8' 1.8' - 2.5' 2.5' - 9' 9' - 10' 10' - 18' 18' - 48'	SILT, banded SAND, coarse, gravelly TILL (gravel 19.3%, sand 45.2%, silt and clay 35.2%, Pw=12.9%, Lw=16.2%) SAND, very coarse TILL TILL (gravel 22.4%, sand 34.4%, clay and silt 43%, Pw=13.8%, Lw=22.7%)
R-39	0' - 20' 0' - 5'	SAND & GRAVEL, esker SAND & GRAVEL (gravel 24.1%, sand 30.4%, silt and clay 45%), crevasse filling
R-40	0' - 150'	SAND & GRAVEL, hummocky, oxidized
R-41		SAND & GRAVEL, glacial channel with terraces (gravel 52.1%, sand 28.8%, silt and clay 18.8%)
R-42	0' - 10' 10' - 12'	TILL, partially cemented by clacite SAND, very fine
R-34	0' - 40' 40' - 70' 70' - 90' 90' - 130'	TILL, stony SAND & SILT TILL (gravel 22.2%, sand 28.4%, clay and silt 49.1%, Pw=12.2%, Lw=25%) SILT & SAND, coarse, pebbles
R-44	0' - 5' 5' - 11' 11' - 21' 21' - 30' 30' - 33' 33' - 53'	TILL, stony SAND, medium to fine TILL, pebbly SAND, medium quartz SAND & SILT TILL (gravel 13.9%, sand 30.9%, silt and clay 54.2%, Pw=15%, Lw=24%)
R-45	0' - 7' 7' - 12' 12' - 18' 18' - 28' 28' plus	SILT TILL, pebbles SILT, medium to fine GRAVEL & SAND, well sorted TILL

MAP SYMBOL

SUMMARY OF DATA

R-46 (section I)	0' - 3.3'	CLAY, silty, traces of coarse sand and fine gravel, frozen below 1.5'
	3.3' - 10'	SAND, coarse & GRAVEL, fine, interbedded
	10' - 10.3'	ORGANIC
	10.3' - 30'	SAND & GRAVEL
(section II)	0' - 1.7'	SILT, clayey
	1.7' - 3.6'	SILT & SAND, crossbedded
	3.6' - 7.2'	SAND, coarse & GRAVEL, fine
	7.2' - 7.5'	ORGANIC
	7.5' - 30'	SAND, coarse & GRAVEL, fine
(section III)	0' - 1.7'	SILT, clayey
	1.7' - 6'	SAND & SILT
	6' - 9'	GRAVEL, medium to fine
	9' - 30'	SAND, coarse & GRAVEL
(section IV)	0' - 3.3'	SILT, clayey
	3.5' - 22'	SAND, coarse & GRAVEL, fine
	22' - 22.3'	ORGANIC
	22.3' - 30'	SAND & GRAVEL
R-47		SHALE, gypsiferous
		GYPSUM
R-48	0' - 15'	TILL
	15' - 16'	SILT & SAND, fine
	16' - 20'	SAND, gravelly
	20' - 20.5'	SILT
	20.5' - 30.5'	SAND & GRAVEL, occasional clay layer
R-49	0' - 30'	TILL, slumped
	30' - 80'	SAND, fine, silty
	80' - 86'	TILL
R-50	0' - 10'	GRAVEL, sandy
	10' - 35'	SAND, coarse & GRAVEL, fine
R-51	0' - 17'	TILL (gravel 18.7%, sand 20.9%, silt and clay 60.4%, Pw=17.2%, Lw=30.8%)
	17' - 26'	ICE, till inclusions
	26' - 28'	TILL & ICE, stratified
R-52	0' - 50'	SAND
	50' - 130'	TILL
	130' - 160'	SAND
R-53	0' - 17'	SAND, gravelly, medium to coarse
	17' - 26'	CLAY, silty
	26' - 38'	SAND, as above
	38' - 55'	VARIABLE, interbedded silt & clay, sand and gravel

MAP SYMBOL

SUMMARY OF DATA

R -54	0' - 8' 8' - 20' 20' - 133'	CLAY & SILT, interbedded COVERED INTERVAL SLUMP, extends to water level
R-55	0' - 40' 40' - 60' 60' - 80'	CLAY, silty, gypsum crystals in seams SAND, medium to coarse, occasional gravel layer SLUMP, extends to water level
R-56	0' - 15' 15' - 60' 60' - 85'	CLAY GRAVEL, sandy SLUMP, extends to water level
R-57	0' - 12.8' 12.8' plus	BOG, frozen from 2', ice up to 50% by volume SAND, medium, becoming gritty and silty
R-58	0' - 65' 65' - 70' 70' - 95'	SILT, clay interbeds toward the bottom SAND & CLAY, interbedded and contorted TILL
R-59	0' - 2.5' 2.5' - 3' 3' - 4' 4' - 10'	SILT, fine sand CLAY, silty SILT, fine sand SILT, very organic
R-60	0' - 40' 40' - 43' 43' plus	TILL SHALE, brecciated SHALE
R-61	0' - 1' 1' plus	TILL, clayey, permafrost at 0.5' SHALE
R-62		CLAY
R-63		TILL, permafrost at 1'
R-64		SILT & SAND, interbedded with gravels, high ice content, extensive slumping
R-65	0' - 2' 2' plus	SAND, fine, silty GRAVEL
R -66	0' - 3' 3' plus	TILL SHALE
R-67	0' - 1' 1' plus	TILL, pebbles SHALE
R-68		TILL, clayey, silty, probed to 2.5' - no permafrost
R-69	0' - 1' 1' - 7' 7' - 9' 9' - 13'	SILT, segregated ice throughout GRAVEL & SAND, segregated ice throughout SAND, fine to medium, segregated ice throughout GRAVEL, well sorted, frozen

MAP SYMBOL	SUMMARY OF DATA	
R-70	0' - 6.5' 6.5' - 19'	ORGANIC, frozen from 5' SILT, clayey, frozen, massive ice present 50% to 90% by volume
R-71		SILT, pebbles, 2' to permafrost
R-72		LIMESTONE, mineral springs (cold)
R-73		CLAY, silty & SILT, clayey, 2.5' to permafrost
R-74	0' - 1.8'	ORGANIC, permafrost at 1.8' still in organics
R-75		TILL, silty, clayey, trace of pebbles
R-76		SILT & CLAY, lacustrine, 1.5' to permafrost
R-77		TILL, clayey, silty, track vehicle prints now eroded to 15'
R-78		TILL, frozen, high ice content
R-79		TILL, frozen at 1.5', pebbles
R-80	0' - 3' 3' - 28'	GRAVEL, medium to coarse TILL
R-81		GRAVEL (89%, sand 7.3%, silt and clay 0.8%)
R-82		TILL (gravel 29.1%, sand 34.3%, silt and clay 36.6%)
R-83		GRAVEL (92.1%, sand 6.3%, silt and clay 1.5%)
R-84 (section I)	0' - 85' 85' - 110' 110' - 160'	SILT, lacustrine SAND TILL (gravel 32%, sand 29%, silt and clay 38.7%, Pw=13.2%, Lw=22.2%)
(section II)	0' - 20' 20' - 35' 35' - 65' 65' - 85' 85' - 115' 115' - 120'	SILT, grading into sand with depth SAND TILL SAND GRAVEL & SAND TILL (gravel 30.1%, sand 35.1%, silt and clay 34.5%, Pw=14.5%, Lw=20.2%)
R-85		GRAVEL (90%, rest sand, silt and clay)
R-86		SAND (96.3%, silt and clay 3.3%)
R-87	0' - 35'	TILL (gravel 9.9%, sand 28.6%, silt and clay 61.3%)

MAP SYMBOL

SUMMARY OF DATA

R-88		SAND (gravel 17.8%, sand 77%, silt and clay 5.1%)
R-89		SAND (gravel 15.9%, sand 83%, silt and clay 1.1%)
R-90		TILL (gravel 17.9%, sand 33.9%, silt and clay 58.2%)
R-91		SAND & GRAVEL, kame
R-92		TILL (gravel 36.4%, sand 40%, silt and clay 23.6%)
R-93		GRAVEL (89.5%, sand 8.2%, silt and clay 1.9%)
R-94		TILL (gravel 3.7%, sand 54.5%, silt and clay 41.8%)
R-95		TILL (gravel 2.3%, sand 42.2%, silt and clay 55.2%)
R-96		GRAVEL (79.7%, sand 17.7%, silt and clay 1.8%)
R-97	0' - 30'	TILL (gravel 26.3%, sand 44.9%, silt and clay 28.7%, Pw=13.2%, Lw=14.8%)
	30' - 45'	SILT & SAND
	45' - 60'	SAND & GRAVEL
	60' - 95'	GRAVEL, very fine
	95' - 117'	GRAVEL & SAND
	117' - 147'	TILL (gravel 28.1%, sand 22.5%, silt and clay 49.1%, Pw=16.4%, Lw=28.1%)
R-98		TILL (gravel 16.6%, sand 21.7%, silt and clay 61.7%)
R-99		SILT (gravel 0.4%, sand 1.7%, silt and clay 97.6%), frozen at 6"
R-100		TILL (gravel 16.2%, sand 27.2%, silt and clay 56.4%), burnt over area

MAP SYMBOL
(date drilled)

FROST AND
MOISTURE DATA

LITHOLOGY AND
ENGINEERING DATA

R-101 (14/10/72)	unfrozen to 0.2', Vx and Vr to 8.3'	0' - 8.3' BOG
	Vx and Vr	8.3' - 8.8' SILT & CLAY, organic
	Vx	8.8' - 11' SILT & SAND

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
R-102 (10/7/72)	unfrozen to 0.3' Vx and Vr to 7.5' Vx, Vr and Vs Vx and Vr	0' - 7.5' BOG 7.5'- 7.7' CLAY, limy, shale rock chips 7.7'- 8.3' TILL, pebbly, stony till
R-103	unfrozen to 0.3', Vx and Vr to 4', ice 35% @ 4' Vx, Vr and Vs, ice 50% @ 5.5' unfrozen	0' - 4' ORGANIC 4' - 9.1' CLAY & SILT 9.1'-14.2' SAND, clayey
R-104	unfrozen to 0.3', Vx and Vr to 10.3', ice 30% @ 3.5' Vr, Vs and ice up to one inch, ice 50% @ 11.5' Vx and Vr	0' -10.3' BOG 10.3'-13.5' SILT, organic 13.5'-15.8' TILL, sandy
R-105	unfrozen to 0.3', Vx and Vr to 6.1' Vr, Vs and ice up to one inch, ice 60% @ 6.8'	0' - 6.1' BOG 6.1'- 7.4' TILL
R-106	unfrozen Vr and Vs, ice 40% @ 1.3', 30% @ 2', 5% @ 6.8'	0' - 0.5' ORGANIC 0.5'- 9' SILT, clayey
R-107	unfrozen to 0.3', Vx and Vr to 3.6' Ice + clay Vx and Vr Vx and Vr Ice + clay Vx and Vr	0' - 3.5' ORGANIC 3.6'- 4.0' CLAY, organic 4.0'- 4.8' ICE with clay lenses 4.8'- 5.3' CLAY 5.3'- 6.3' ORGANIC 6.3'- 7.3' ICE with clay lenses 7.7'- 8.1' CLAY, silty
D-1	Nf, w=13% @ 2.5' 12% @ 7.5', 8% @ 12.5'	0' -15' TILL, clayey
D-2	Nf, w=13% @ 2.5' 11% @ 12.5'	0' -15' TILL, clayey
D-3	Nf, w=14% @ 2.5' 11% @ 7.5', 10% @ 12.5'	0' -15' TILL, clayey

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
D-4	Vr Vr to 9', unfrozen to 11', frozen to 15'	0' - 0.5' ORGANIC 0.5'-15' TILL, clayey
D-5	Nf, w=7% @ 5' Nf, w=6% @ 10' Nf, w=5% @ 15'	0' - 7' TILL, clayey 7' -12' CLAY 12' -25' SILTSTONE
D-6	Nf to 2.5', Vx to 15' w=17% @ 2.5' 20% @ 7.5' 12% @ 11'	0' -15' TILL, clayey
D-7	Nf to 3', Vx to 8' w=8% @ 3' Vx, w=12% @ 11', 15% @ 14'	0' - 8' SAND 8' -15' TILL, clayey
D-8	Nf, w=10% @ 2.5', 15% @ 7.5', 12% @ 12.5'	0' -15' TILL, clayey
D-9	Nf, w=18% @ 2.5', 6% @ 8', 12% @ 12.5'	0' -15' GRAVEL
D-10	Vx, w=16% @ 2.5', 12% @ 7.5', 13% @ 12.5'	0' -15' SAND
D-11	Nf, w=11% @ 2.5' Nf, w=11% @ 7.5' 12% @ 12.5'	0' - 3.5' SAND 3.5' - 15' TILL, clayey
D-12	Nbn, w=12% @ 2.5' and 7.5', 13% @ 12.5'	0' - 15' SILT
D-13	Nbn Nbn, w=12% @ 7.5', 8% @ 12.5'	0' - 2' SAND 2' - 15' TILL, clayey
D-14	Nf, w=22% @ 5' Nf, w=15% @ 10', 12% @ 15'	0' - 9' TILL, clayey 9' - 12' SILT
D-15	Nf, w=12% @ 5', 13% @ 10', 13% @ 15'	0' - 15' GRAVEL
D-16	Nf, w=13% @ 5', 16% @ 10', 12% @ 15'	0' - 15' TILL, clayey

MAP SYMBOL (date drilled)	FROST AND MOISTURE DATA	LITHOLOGY AND ENGINEERING DATA
D-17	Nbn Nbn, w=14% @ 2.5', 13% @ 7.5', 13% @ 12.5'	0' - 2' SAND, silty 2' - 15' TILL, clayey
D-18	Vx Vx to 8, Nf to 15' w=13% @ 8', 17% @ 12.5'	0' - 6' ORGANIC 6' - 15' TILL, clayey
D-19	Nf Nf, w=18% @ 5', 17% @ 10', 12% @ 15'	0' - 4' SAND 4' - 12' TILL, clayey
D-20	Nf Nf, w=18% @ 5', 19% @ 10', 12% @ 13'	0' - 4' GRAVEL 4' - 15' TILL, clayey
D-21	Nf, w=8% @ 4' Nf, w=11% @ 9' Nf, w=14% @ 14'	0' - 6.5' GRAVEL 6.5' - 11.5' SAND 11.5' - 15' SAND, silty
D-22	Nbn, w=12% @ 5', 15% @ 10', 17% @ 15'	0' - 15' TILL, clayey
D-23	w=16% @ 2.5', 17% @ 7.5', 13% @ 12.5'	0' - 15' TILL, clayey
D-24	Nf, w=18% @ 5', 12% @ 10' and 15'	0' - 15' SAND
D-25	Nf, w=16% @ 2.5', 13% @ 7.5', 18% @ 12.5'	0' - 15' TILL, clayey
D-26	Nf, w=11% @ 2' Nf, w=15% @ 7'	0' - 4' CLAY 4' - 10' TILL, clayey

11. APPENDIX B. GROUNDWATER DISCHARGE
(by R. O. van Everdingen)

11.1 Map symbols

Locations mentioned in this appendix are marked on maps 2, 3 and 4 by consecutive numbers preceded by the letter V.

11.2 Introduction

Evidence of groundwater discharge is found in the form of springs, seeps, baseflow in rivers, and lakes or ponds with mineralised water. In the area of discontinuous permafrost the discharge can be derived from the active layer, or from below and through unfrozen zones in the permafrost. The dissolved mineral content of the groundwater discharge is related (in terms of total concentration and relative composition) to the length of the underground flowpath and to the lithology traversed by the water.

The occurrence of groundwater discharge can affect engineering projects (roads, pipelines, etc.) in a number of ways. These include instability of slopes, development of quick conditions in relatively fine-grained materials, growth or melting of ice lenses (depending on natural and man-made temperature regime), and formation of seasonal or perennial icings (aufeis deposits).

In view of the potential engineering problems associated with groundwater discharge, a detailed survey of active discharge areas should be included in the studies for final route selection for pipelines and highways in the permafrost area. Data in the next section of this appendix, derived from both published and unpublished sources in government and industry, illustrate the occurrence of groundwater discharge within the Mackenzie Valley Transportation Corridor. Groundwater discharge is undoubtedly more widespread than indicated by the data presented here.

11.3 Summary of observations

11.3.1 Area II - Map 2.

V-1, 2 and 3 -

Springs with a high iron and sulfate content (total dissolved solids 758 milligram/liter) and a low pH of about 4.5. Discharge rate estimated at between 10 and 25 gpm (gallons per minute).

11.3.2 Area III - Map 3.

V-4 -

Group of springs at the base of the slope of Mount Camsell. No details available.

V-5 -

Series of springs at the base of Mount Camsell, depositing travertine. No other details available.

11.3.3 Area IV - Map 4.

V-6 -

Group of at least three springs on right bank of Willowlake River. High calcium and sulfate contents (535 and 1445 mg/l); total dissolved solids between 2000 and 2300 mg/l. Individual discharge rates range from about 200 to almost 1000 gpm; perennial flow; temperature 13 - 17° C.

V-7 -

Seepage area on SW side of winter road. Water has elevated Ca, Na, Cl and SO₄ contents; total dissolved solids 900 to 1000 mg/l. Temperature 7.5°C; discharge from individual seepages probably less than 1 gpm.

V-8 -

Ponds fed by springs on NE side of winter road. Springwater temperature about 10°C; discharge rate could be as much as 50 gmp; total dissolved solids around 2000 mg/l.

V-9 -

Discharge from spring area on slope above winter road, from small pond on NE side of winter road, and from large pond on SW side of winter road. High contents of Ca, Na, Cl and SO₄; total dissolved solids ranging from 3500 to 4500 mg/l. Temperature 8 - 11°C; discharge rate at least 330 gpm. Travertine being deposited. Discharge throughout winter.

V-10 -

Seepage area between winter road and base of slope. Extensive deposits of travertine; marshy area with ponds. High calcium and sulfate contents; total dissolved solids about 2300 mg/l. Temperature between 9 and 11°C.

V-11, 12, 13 -

Groups of springs along Smith Creek. At point V-13 spring water has high Ca, Na, Cl and SO₄ content and total dissolved solids of 2575 mg/l; temperature 14°C; combined discharge rate about 50 gpm. Total dissolved solids 685 mg/l and temperature 3°C at V-12. Some aufeis development.

V-14 -

Spring on Hodgson Creek. Total dissolved solids varies from 420 to about 450 mg/l; temperature 2 - 4°C.

V-15 -

Roche-qui-trempe-à-l'eau - Warm springs, temperature 27.5°C. High contents of Na, Cl, Ca and SO₄; total dissolved solids between 12,000 and 13,000 mg/l. Discharge rate at least 100 gpm. Travertine deposit. Water in the creek one mile north of the springs had a total dissolved content of slightly over 9800 mg/l, and a temperature of 21°C. (Brandon, 1965, GSC paper 64-39).

V-16 -

Spring on creek north of Ochre River. Total dissolved solids varying between 340 and 425 mg/l; temperature 1.5 - 4°C. Discharge rate about 300 gpm. Extensive aufeis development in winter.

V-17 -

Springs on "Big Section" Creek. Several springs, some of which deposit iron hydroxide. Temperatures around 5°C. High contents of Na, Cl, Ca and SO₄; total dissolved solids 5660 mg/l. Discharge rates from less than 1 gpm to about 25 gpm for individual orifices. Aufeis development in winter.

V-18 -

Springs on tributary of Blackwater River. Major ions are Ca and SO₄; total dissolved solids range from 630 to about 900 mg/l; temperature 2.5 - 3°C. Large aufeis deposits developed in winter.

LIBRARY
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AREA 12 DATA LOCATION
SOUTH-CENTRAL REGION
MACKENZIE AND LIARD RIVERS,
MARTIN HILLS
MAP SHEETS
Southwestern part Mills Lake (65 E)
Ft Simpson (95 H)
Eastern part Sibbeston Lake (95 G)

Southwestern part Mills Lake (85 E)

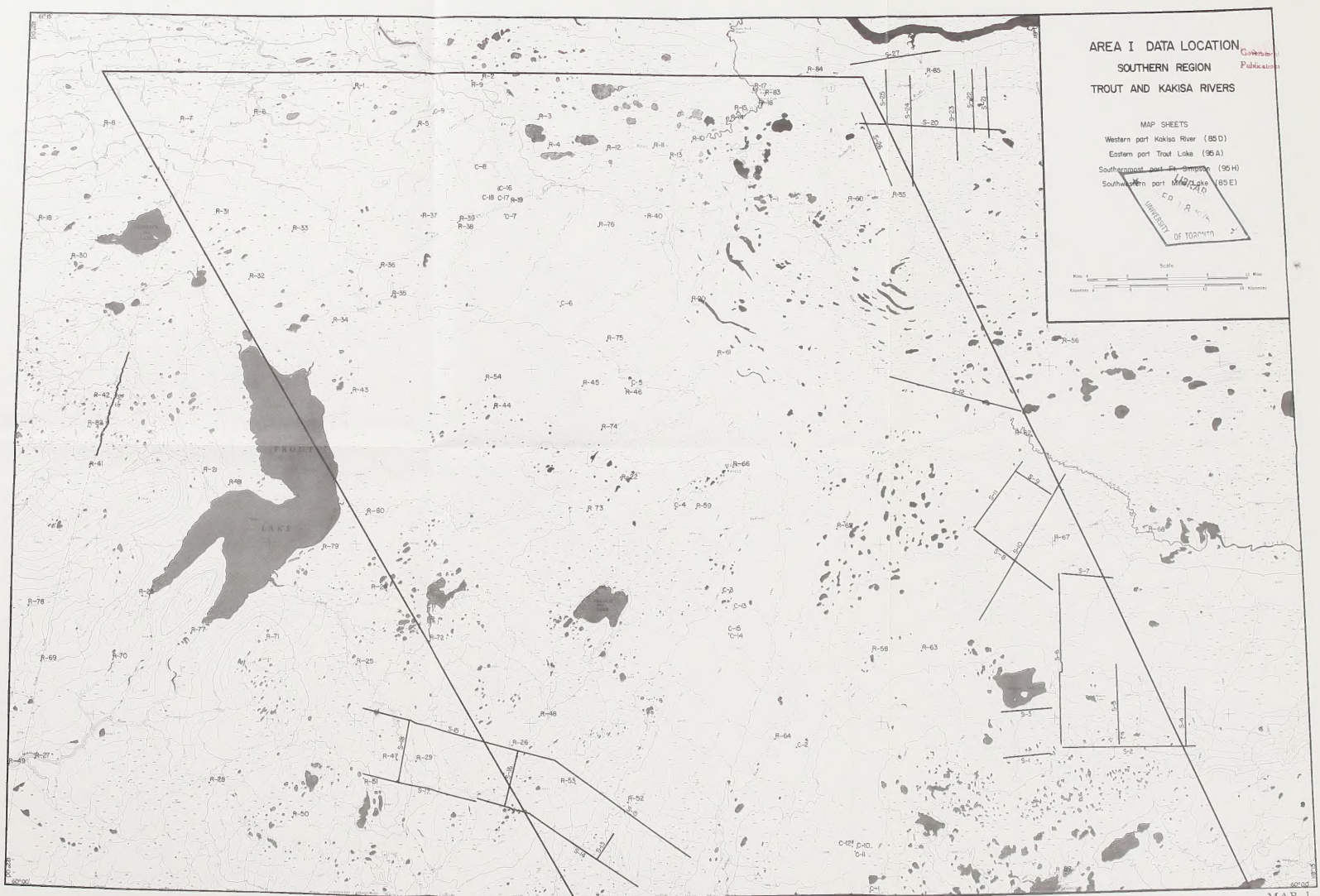
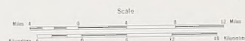
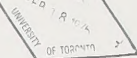
Ft. Simpson (95 H)

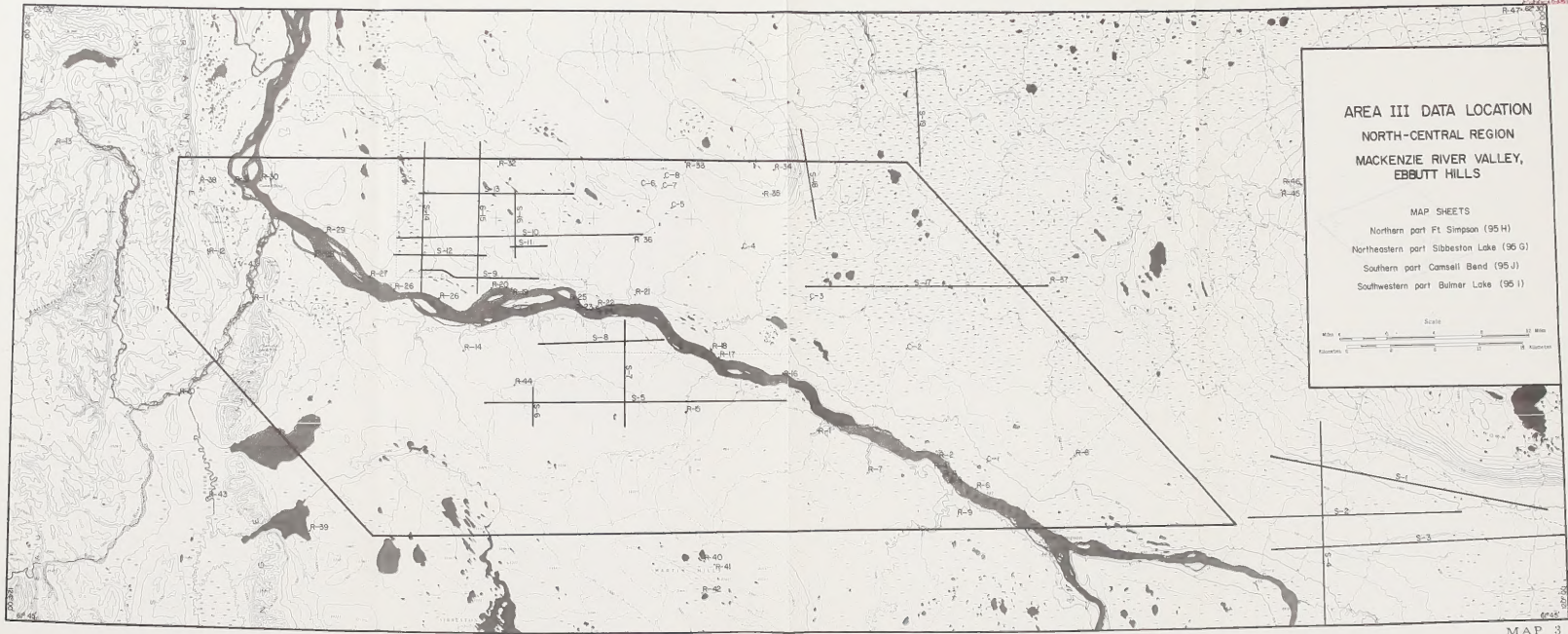
Eastern part Sibbeston Lake (95 G)



AREA I DATA LOCATION
SOUTHERN REGION
TROUT AND KAKISA RIVERS

MAP SHEETS
Western part Kakisa River (85D)
Eastern part Trout Lake (96A)
Southernmost part Simpson (95H)
Southern part Trout Lake (85E)





AREA III DATA LOCATION
NORTH-CENTRAL REGION
MACKENZIE RIVER VALLEY,
EBBUTT HILLS

MAP SHEETS

- Northern part Ft Simpson (95 H)
- Northeastern part Sibbeston Lake (96 G)
- Southern part Camell Band (95 J)
- Southwestern part Bulmer Lake (95 I)



AREA IX DATA LOCATION
NORTHERN REGION
EBBUTT HILLS, WRIGLEY

MAP SHEETS

Southeastern part Bulmer Lake (96 I)

Cansall Bend (96 J)

Wrigley (96 O)

Eastern part Dahodine (96 N)



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